SEDIMENTOLOGY OF THE NEOGENE ALMERÍA BASINS: AN ILLUSTRATED GUIDE.

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Cabo de Gata (English version)

Geological setting

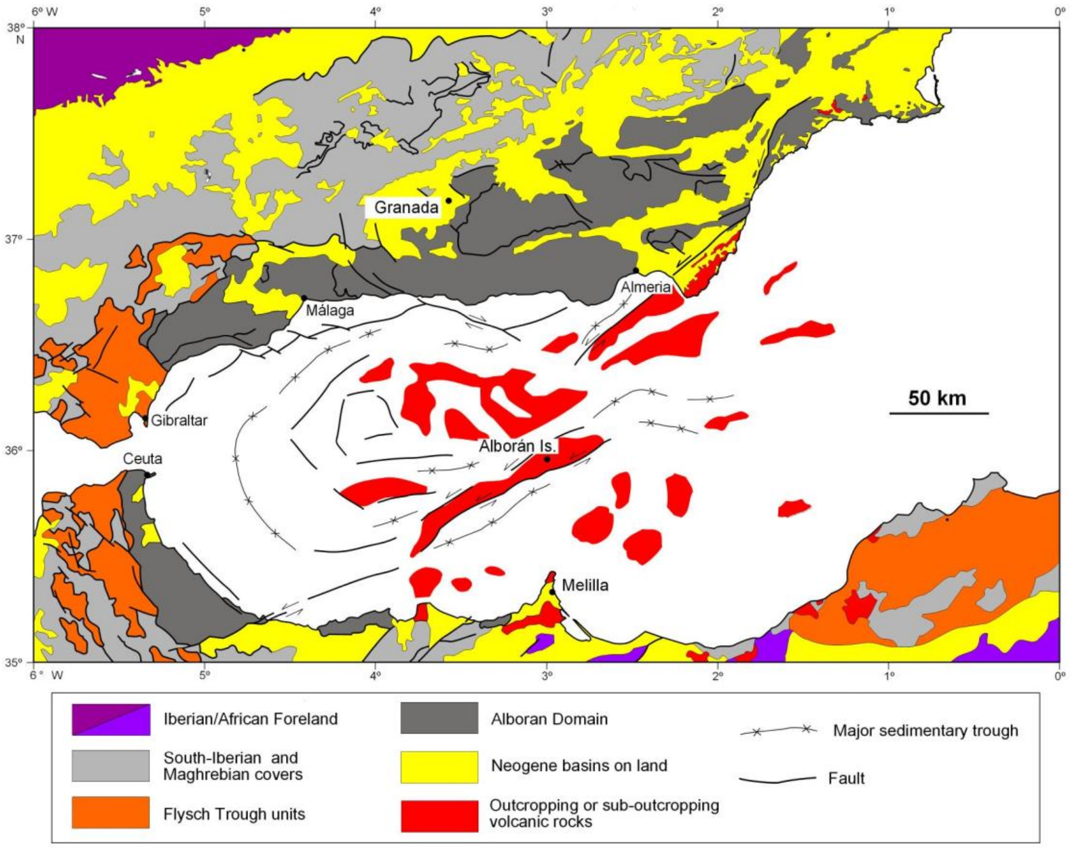


Figure 19. Simplified geological sketch map of the Alborán Sea and distribution of Neogene volcanic rocks. EAB: Eastern Alborán Basin; SAB: Southern Alborán Basin; WAB: Western Alborán Basin; YB: Yusuf Basin (from Comas et al., 1996).

The Carboneras and Palomares faults

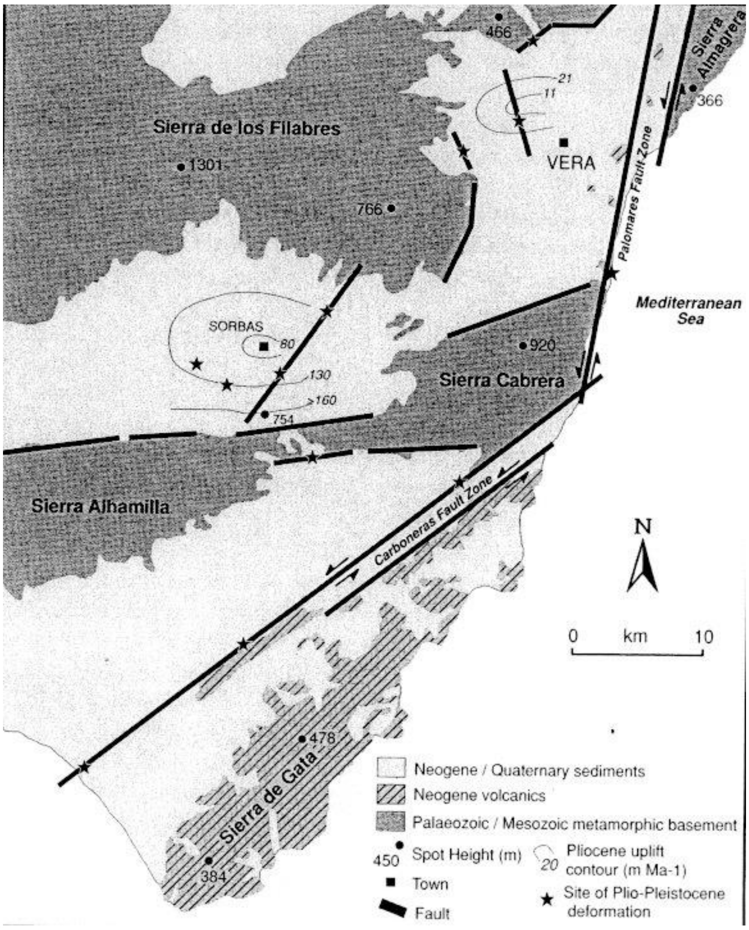
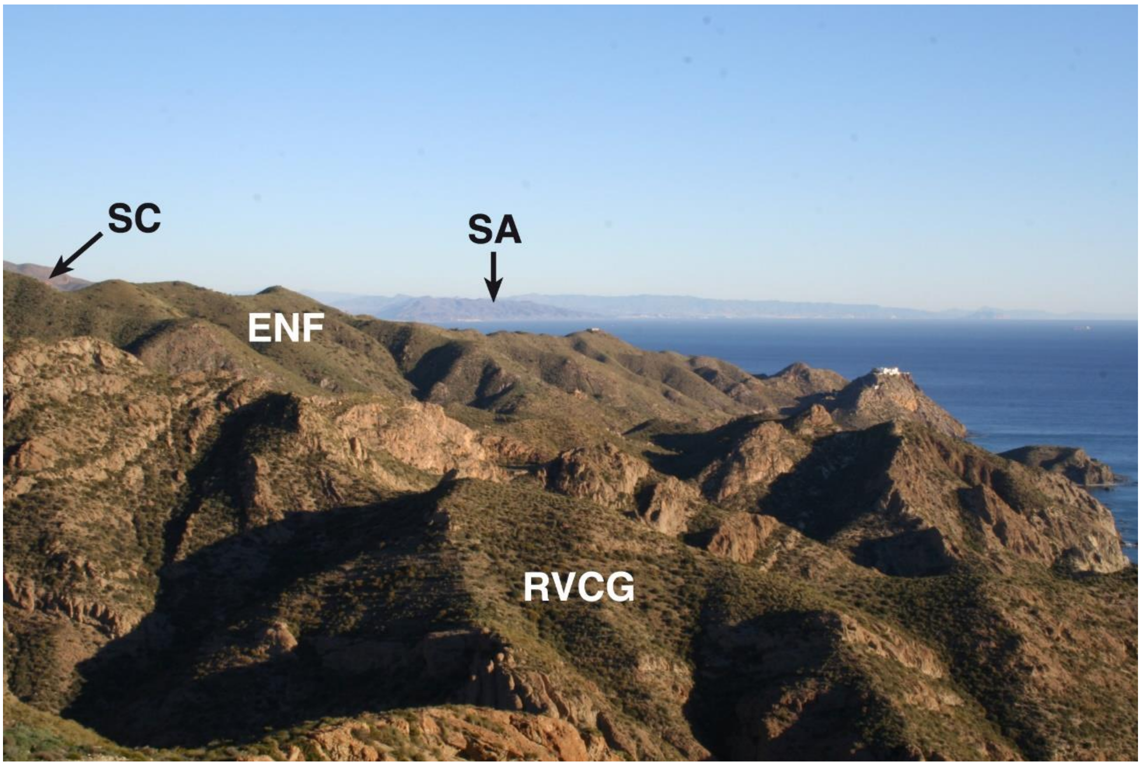


Figure 20. Simplified geological map showing the position of the Carboneras and Palomares strike-slip fault zones (modified after Mather, 1991 and Stokes, 1997).

Photograph 100.- The Carboneras fault marks the northern limit of the Cabo de Gata Volcanic Complex. This strike-slip, sinistral fault puts in contact Palaeozoic metamorphic rocks (Nevado-Filábride basement schists) (on the left side of the picture) (ENF) with Neogene volcanic rocks from the Cabo de Gata Volcanic Complex (on the right side of the picture) (RVCG) (Sierra Cabrera. Rambla de la Granatilla. Sopalmo).→

Photograph 101.- The fault zone corresponds to a relatively wide band where huge portions of different materials (Alpujárride carbonates and phyllites, Nevado-Filábride schists, Miocene marls and calcarenites, etc.), which display distinctive strong colours, outcrop. They usually are sub-vertically arranged and heavily fragmented in places. They were dragged from different areas at times the fault moved, and placed together along the fault in a chaotic manner (Sierra Cabrera. Rambla de la Granatilla. Sopalmo).

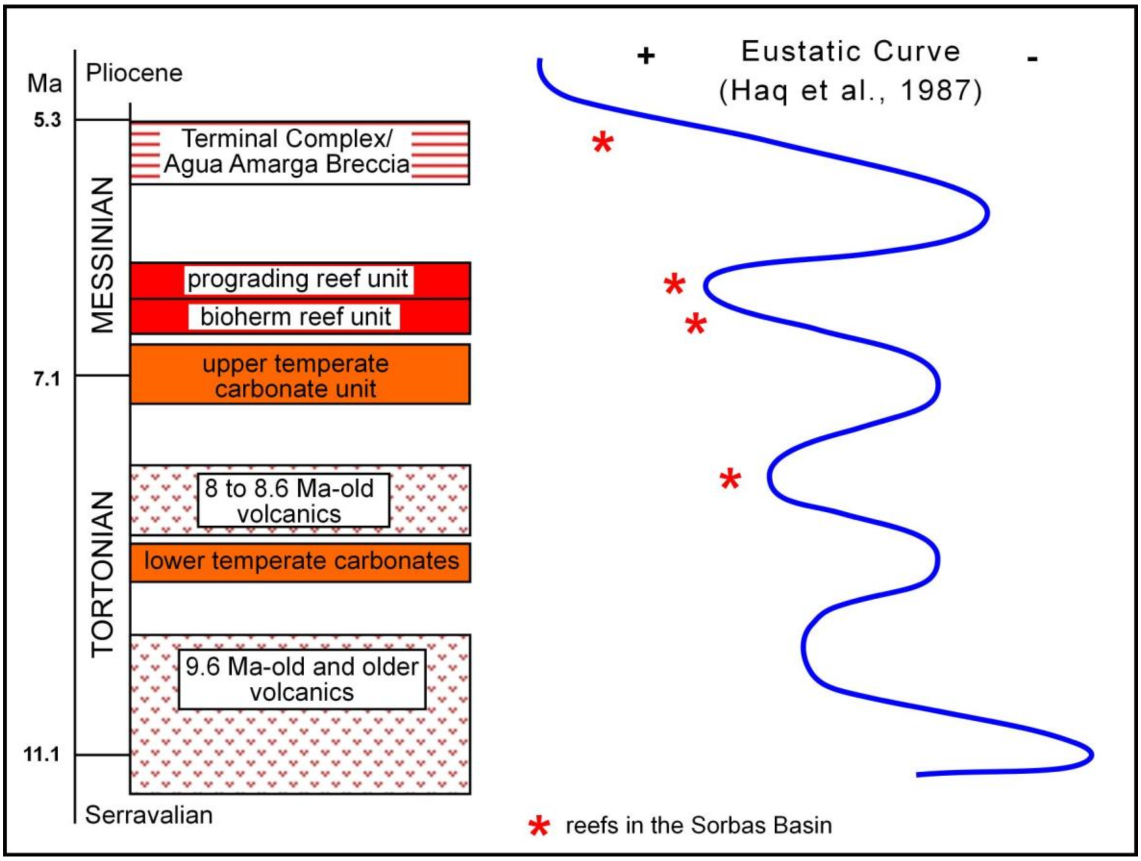


Photograph 102.- The view to the North shows the Neogene volcanic rocks of the Cabo de Gata Volcanic Complex (RVCG) at the foreground, and the Palaeozoic or older metamorphic rocks (Nevado-Filábride basement schists) (ENF) at the background. They are separated now by the Carboneras strike-slip fault. The Triassic carbonates of Sierra de Cabrera (SC), on the left side, and Sierra Almagrera (SA), on the right side, are seen at the distance. Both sierras initially formed part of a single relief, which was cross-cut and splitted by the sinistral Palomares strike-slip fault (developed as a continuation of the Carboneras fault to the North). They have been displaced one from the other for more than 20 km since their separation started in the late Miocene (Sierra Cabrera. Cerro de los Santos).

The volcanic rocks

The volcanic episodes

Figure 21. (a): Neogene stratigraphy of the Agua Amarga Basin in the northern Cabo de Gata. The position of the two volcanic episodes (the one at the base and the one at the middle of the sequence) clearly stands out (modified from Braga et al. 1996). (b): Chronostratigraphy of Miocene sedimentary rocks in Agua Amarga Basin and their correlation to the eustatic curve (Haq et al. 1987). Temperates carbonates were deposited during low sea-levels of third-order cycles while coral reefs grew during high sea-levels. Absolutes ages after Hilgen (1991) and Bergreen et al. (1995) (from Braga et al. 1996). →



Photograph 103.- The Cabo de Gata Volcanic Complex in the Rodalquilar area. Most of the volcanic rocks originated during the first episode of vulcanism. Only the two domes located at the topmost part of Los Frailes (LF) relate to the second phase of vulcanism. Post-volcanic sedimentary rocks (upper Tortonian-Messinian carbonates) occur at Cerro de la Molata (CM), on the left side of the picture (Sierra de Cabo de Gata. Ricardillo).

Photograph 104.- Volcanic cones have been significantly destroyed and dismantled by erosion in Cabo de Gata, so that only their most internal parts remain and are now clearly seen and recognized. Volcanic domes stand out. They formed when the lava solidified at the chimney in its way up to the surface. Volcanic rocks from the domes exhibit the typical columnar (sometimes fan-array) jointing (Sierra de Cabo de Gata. Punta Baja).

Photograph 105.- Volcanic rocks range in composition from dacites to basaltic andesites in Cabo de Gata. In the picture, large, black hornblende phenocrystals stand out in the light-colour (acid-rich) microcristaline dacite matrix (Sierra Cabrera. Cerro de los Santos).

Photograph 106.- Volcanic eruptions in Cabo de Gata took place in many different ways (as ignimbrites, lava flows, etc.). Common features are volcanic agglomerates. The look very much like sedimentary conglomerates, although both the “pseudo-clasts” and the matrix are made up of volcanic material. The volcanic blocks (“pseudo-clasts”) presumably are large, dissagregated fragments of the former volcanic chimney incorporated by the new magma as it was making its way up to the surface during a subsequent eruption (Sierra Cabrera. Cerro de los Santos).

The intravolcanic sedimentary episode: The Tortonian temperate carbonates

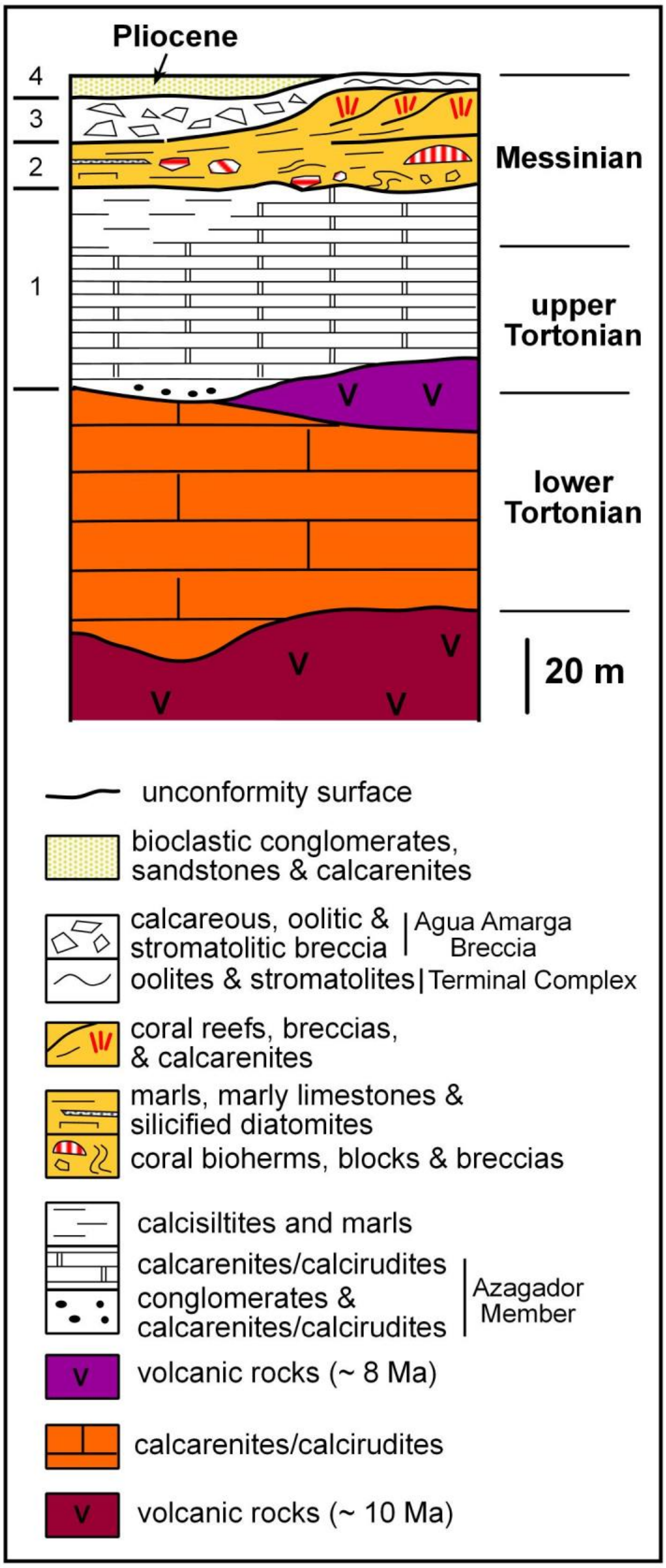


Figure 22. (a): Stratigraphy of the Agua Amarga Basin and northern Sierra de San Pedro (from Braga et al. 1996; modified after Martín et al. 1996).

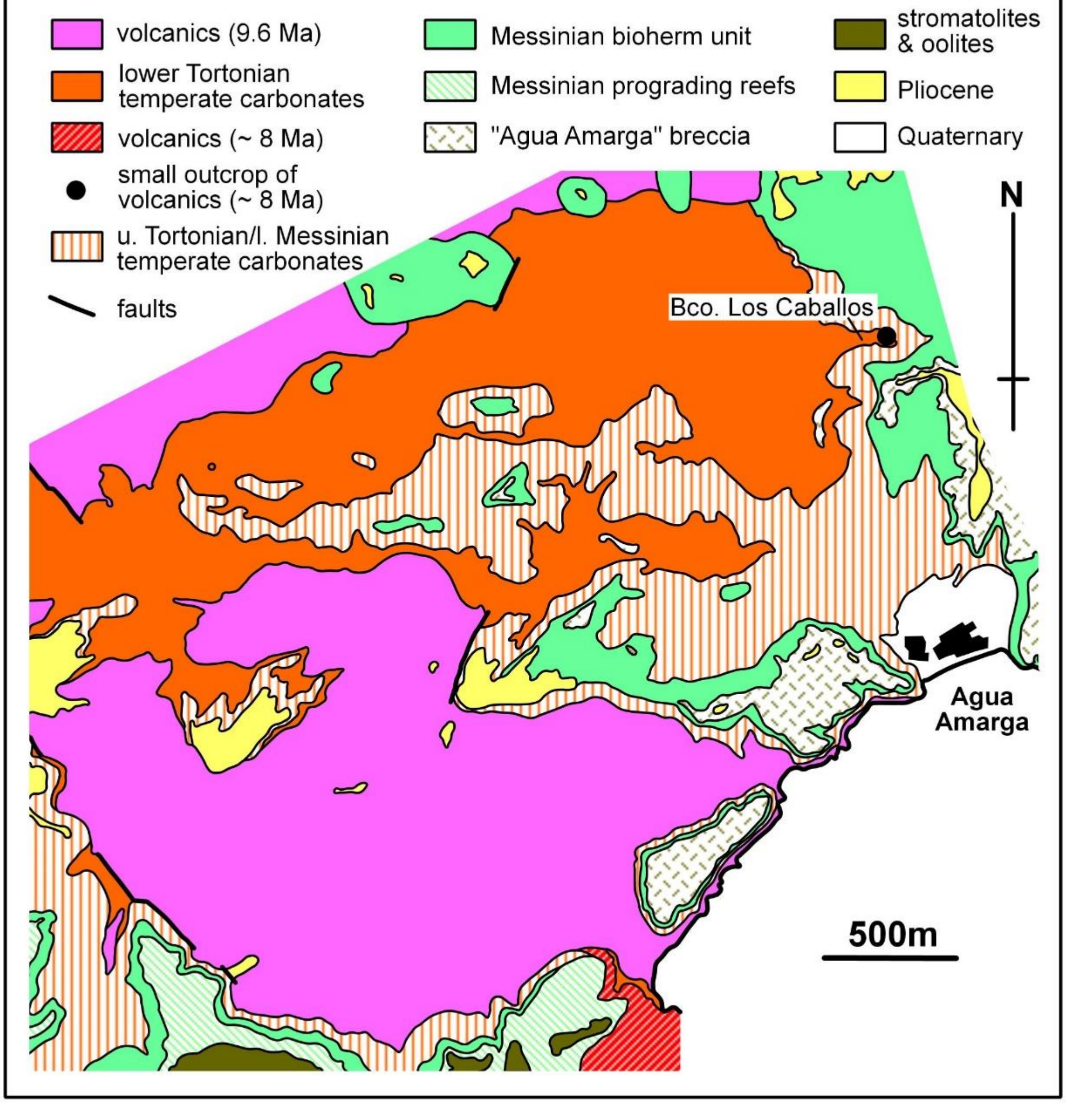
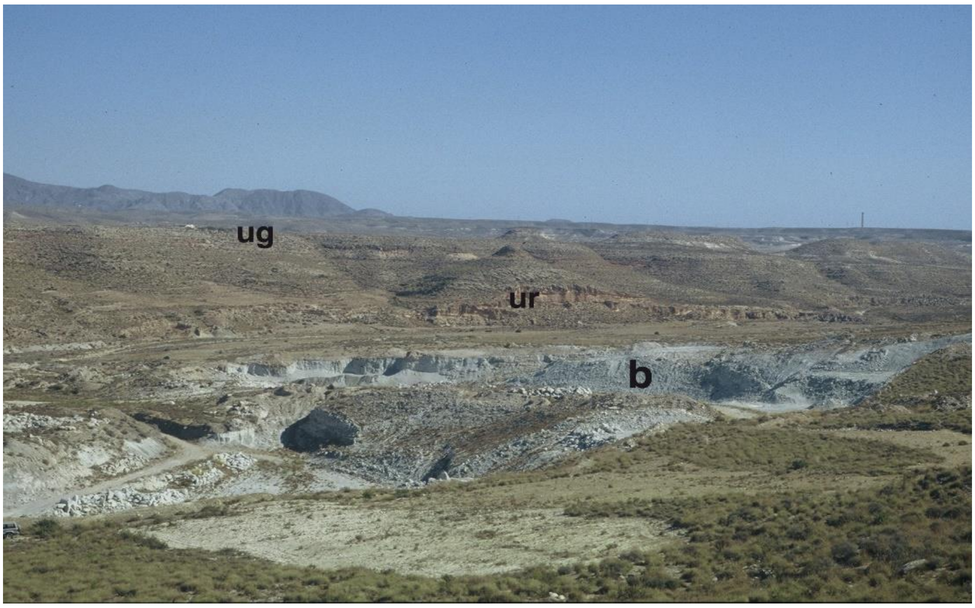


Figure 22. (b): Detailed geological map of the Agua Amarga Basin and northern Sierra de San Pedro (from Braga et al. 1996; modified after Martín et al. 1996).

← Photograph 107.- Miocene intravolcanic sedimentary rocks crop out extensively in the Agua Amarga Basin (CA), situated just West of the Agua Amarga village (Mesa de Roldán).



Photograph 108.- The carbonates from the intravolcanic sedimentary unit are Tortonian in age. They are platform-carbonates, red in colour (they constitute the so-called red unit) (ur), and formed on temperate seas. They overlie volcanic rocks, from the first episode of vulcanism, altered to bentonites (b). In most places in the Agua Amarga basin they are in turn overlain by the post-volcanic uppermost Tortonian-lowermost Messinian temperate carbonates, which exhibit a distinctive grey colour (they constitute the so-called grey unit) (ug) (Agua Amarga Basin. Cañada de Méndez).

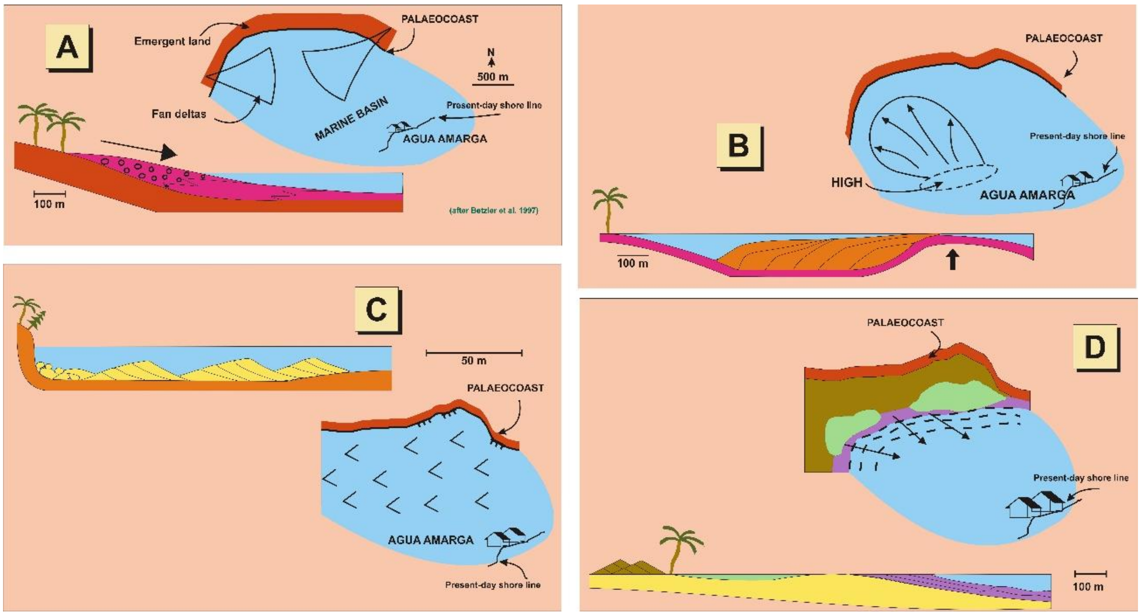


Figure 23. Sequence of evolution of depositional systems in the Agua Amarga basin during the Tortonian from (1) volcaniclastic fans, to (2) washover fans behind a submarine high (swell), to (3) a submarine dune (shoal) field and to (4) a prograding beach system (modified after Betzler et al. 1997).

Photograph 109.- Some very distinctive zones (a, b, c y d) can be differentiated in a vertical section within the “red unit”. Sediments accumulated in precise and specific sedimentary environments such as: (a) washover fans, (b) submarine dunes, (c) beaches and (d) the “lagoon” (Agua Amarga Basin. Cañada de Méndez).

Photograph 110.- Tabular cross stratification is the most distinctive feature in the washover-fan sediments (Agua Amarga Basin. Cañada de Méndez).

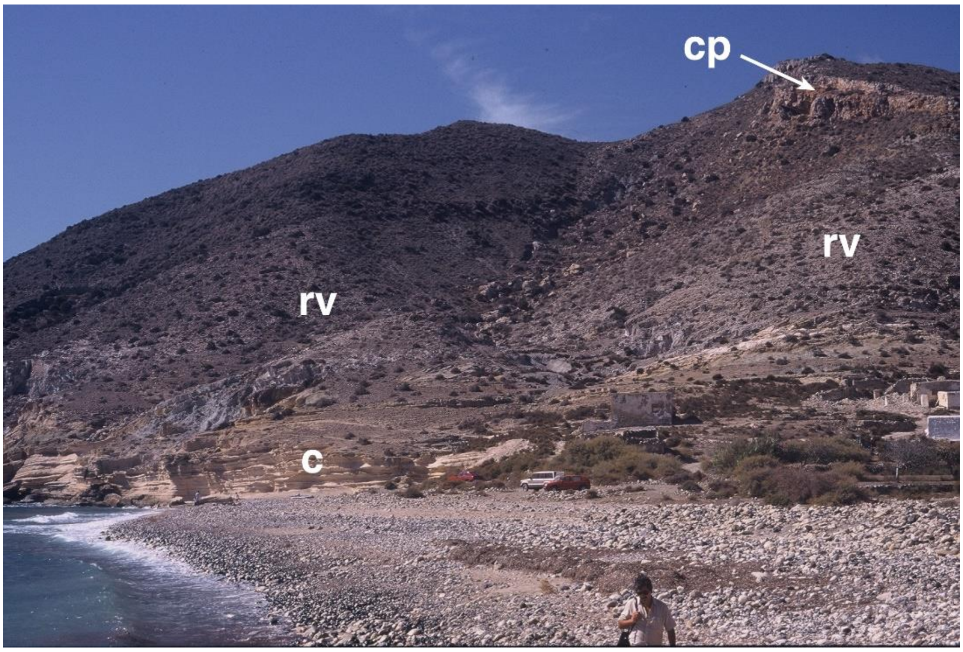
Photograph 111.- Tabular cross-bedded sets are separated by extensive, horizontal surfaces resulting from storm erosion (Agua Amarga Basin. Cañada de Méndez).

Photograph 112.- *Scolicia* burrows, linked to irregular echinoids, abound in some layers (Agua Amarga Basin. Cañada de Méndez).

Photograph 113.- Submarine-dune facies exhibit trough cross-bedding as the most prominent feature. Bedsets are here limited by ondulated surfaces (Agua Amarga Basin. Cañada de Méndez).

Photograph 114.- Low-angle, parallel lamination is the most characteristic sedimentary structure from the beach facies (Agua Amarga Basin. Cañada de Méndez).

The carbonates intercalated and/or engulfed inside the volcanic rocks



Photograph 115.- Tortonian carbonates covered by volcanic rocks (rv) from the second episode of vulcanism in Cabo de Gata. These volcanic rocks are in turn overlain by the uppermost Tortonian-Messinian, post-volcanic carbonates (cp) (Cabo de Gata. Cala del Plomo).

Photograph 116.- Tortonian carbonates underneath volcanic rocks from the second episode of vulcanism (Cabo de Gata. Cala del Plomo).

Photograph 117.- Sedimentary rocks (es) within volcanic rocks (rv). Huge blocks of Tortonian carbonates, of considerable size, were dragged by the extruding magma during the second episode of vulcanism and appears now completely engulfed by the volcanic rocks at some localities (Cabo de Gata. Cala Carnaje).

Photograph 118.- A close view reveals that the contact in detail between the two types of rocks is very irregular (Cabo de Gata. Cala Carnaje).

Photograph 119.- Volcanic agglomerates drapping Tortonian carbonates (Cabo de Gata. Cala Carnaje).

Photograph 120.- Some of the original sedimentary structures (such as cross-bedding) can still be recognised inside the blocks (Cabo de Gata. Cala Carnaje).

The post-volcanic sediments. Temperate carbonates from the Tortonian-Messinian transition. The Agua Amarga carbonate ramp

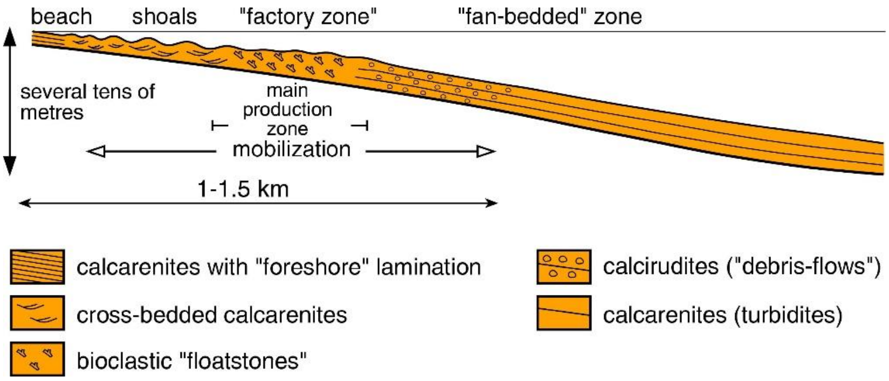


Figure 24. (a): Depositional model for the temperate carbonates of the Tortonian-Messinian transition in the Agua Amarga Basin. These carbonates were deposited on a gentle ramp, in a series of different subenvironments. A beach system formed at the coast. In front of the beach, a shoal area developed. Calcareous organisms lived prolifically in a narrow area (“factory zone”) located immediately seawards of the shoals. Further offshore the so-called “fan-bedded” zone occurs, consisting of gently dipping, sloping beds, thickening downslope. (from Martín et al. 1996).

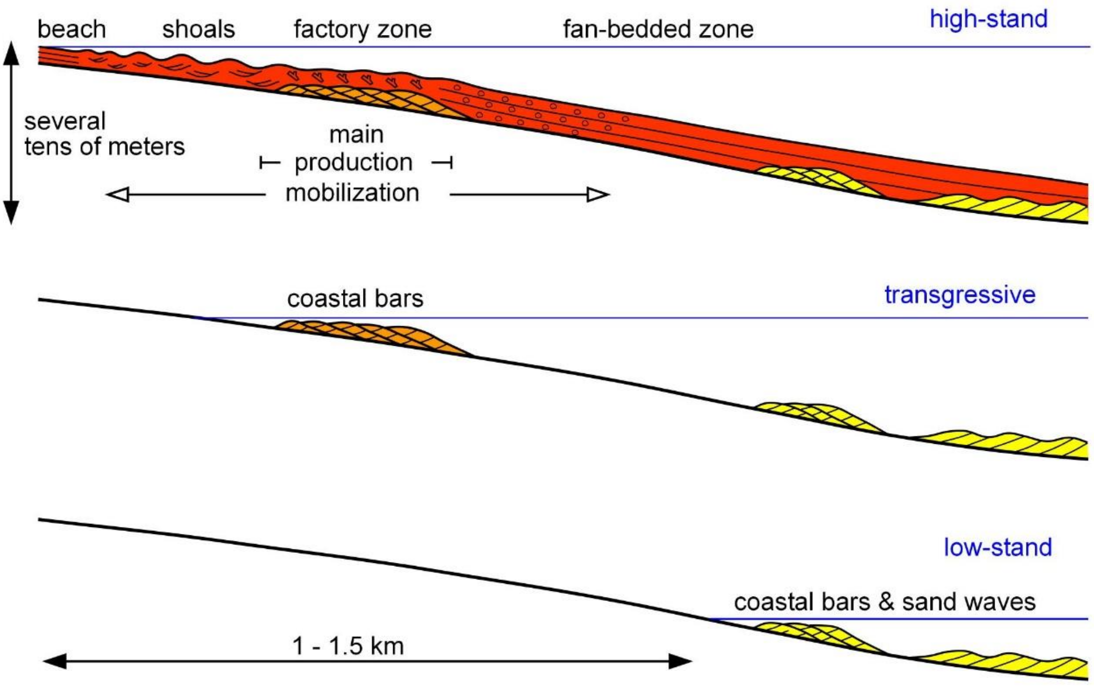


Figure 24. (b): High-frequency, internal cyclicity of the temperate carbonates of the Tortonian-Messinian transition in the Agua Amarga Basin. In the lowstand stage, coastal bars and sand waves developed at a low point down the ramp. In the transgressive stage, they shifted to a higher position. At the highstand stage all these sediments were covered and buried by the highstand deposits described above (from Martín et al. 1996).

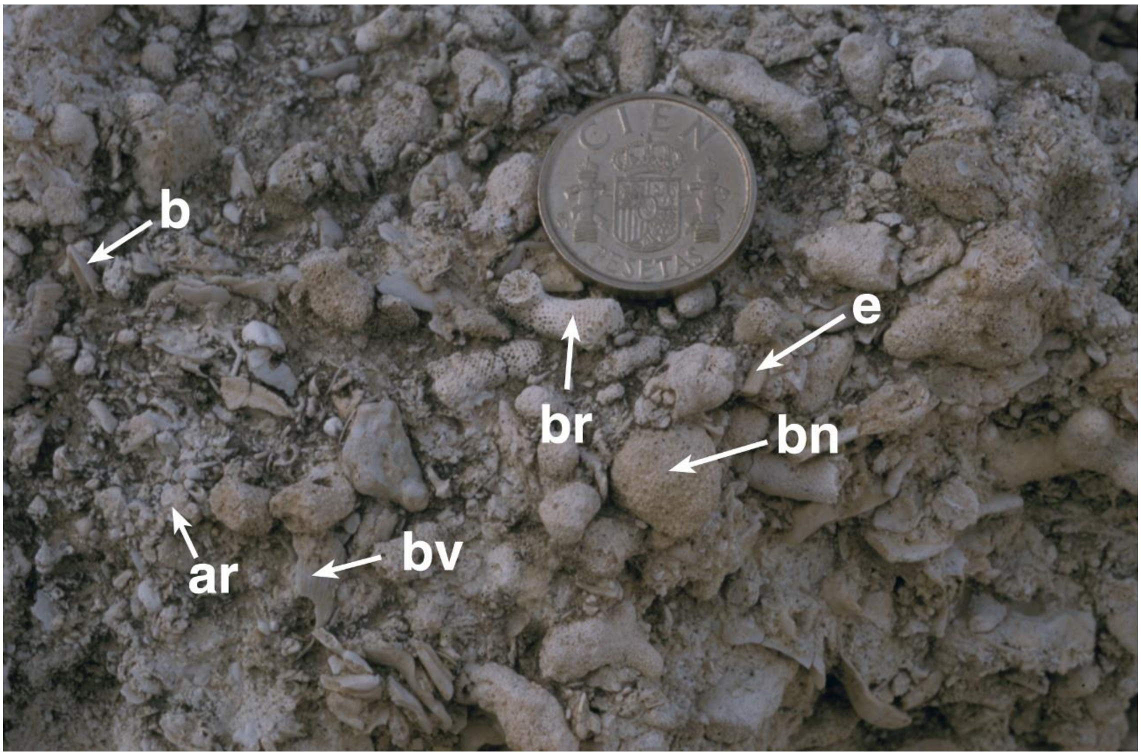
Photograph 121.- Beach deposits exhibiting foreshore, low-angle parallel lamination (Agua Amarga Basin. Los Murcias).

Photograph 122.- Shoal deposits with decametre-scale, trough cross-bedding (Agua Amarga Basin. Las Cordilleras).

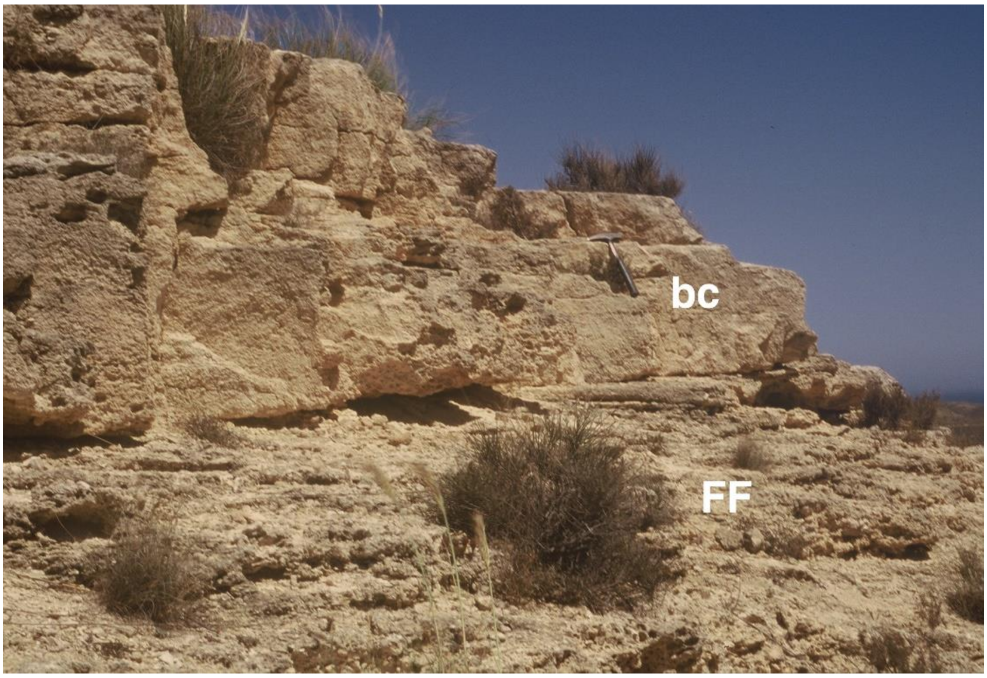
Photograph 123.- Factory facies outcrop from the Tortonian-Messinian transition carbonates (grey unit), just behind the water-well. In this outcrop, they lie directly on top of the intravolcanic Tortonian temperate carbonates (red unit). The Mesa de Roldán stand out at the distance. This is a volcanic relief (formed during the second episode of vulcanism) capped by Messinian coral reefs (Agua Amarga Basin. Las Cordilleras).

Photograph 124.- Field view of the factory facies. Subspherical, nodular bryozoan growths stand out (Agua Amarga Basin. Las Cordilleras).

Photograph 125.- Close view of the factory facies showing abundant nodular bryozoan remains (Agua Amarga Basin. Las Cordilleras).



Photograph 126.- Apart from the nodular bryozoan remains (bn) there also occur fragments of branching bryozoan (br), barnacles (b), echinoids (e), bivalves (bv) and red algae (ar) (Agua Amarga Basin. Las Cordilleras).



Photograph 127.- The factory facies (FF) intercalate with calcarenite (calcirudite) bars (bc). This interbedding relate to high-frequency cyclity (Agua Amarga Basin. Las Cordilleras).

Photograph 128.- Calcarenite (calcirudite) bars are frequently amalgamated (fused together) and show a difuse, internal cross-bedding (Agua Amarga Basin. Las Cordilleras).

Photograph 129.- Distal-ramp deposits show a fan-bedded arrangement (Agua Amarga Basin. Rambla de los Viruegas).

Photograph 130.- Close view showing a couple of banks with cross-bedding intercalated within the distal-ramp deposits of the fan-bedded zone. They formed during lowstand intervals of high-frequency sea-level cycles (Agua Amarga Basin. Rambla de los Viruegas).

Photograph 131.- Bioclastic sediments from the upper part of the distal ramp contain abundant bryozoan remains. These debris flow deposits were mobilized from the factory area and displaced downslope (Agua Amarga Basin. Rambla de los Viruegas).

The small Ricardillo depression

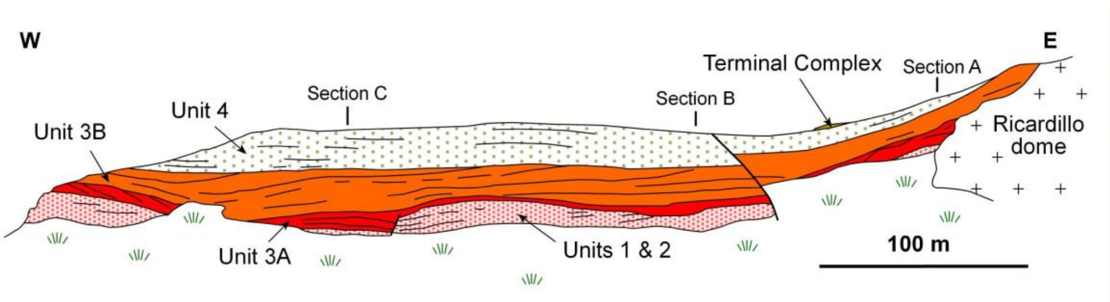


Figure 25. (a): Geological cross-section showing present-day outcrop distribution of succesive temperate-carbonate units deposited on top of the volcanic rocks at the western flank of Monte Ricardillo dome. Lower units (units 1 to 3A) infill a small depression flanked by the volcanic rocks (from Betzler et al. 2000).

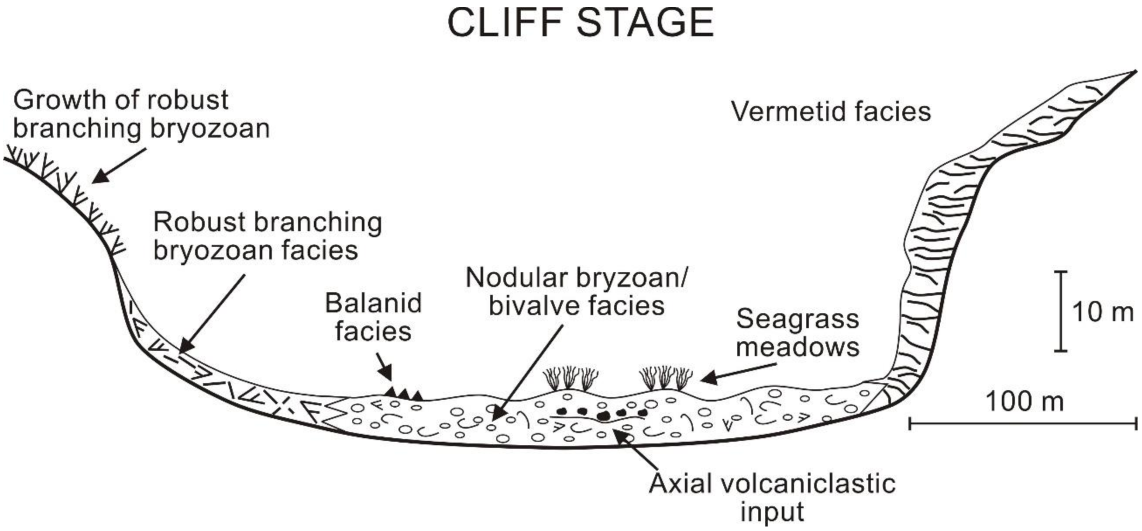


Figure 25. (b): The initial submarine depression was limited by steep submarine cliffs which were colonized either by vermetids or by robust branching bryozoans. Slope aprons of robust branching bryozoan facies formed at the foot of the latter submarine reliefs. In the central part of the depression nodular bryozoan and bivalve remains accumulated (from Betzler et al. 2000).

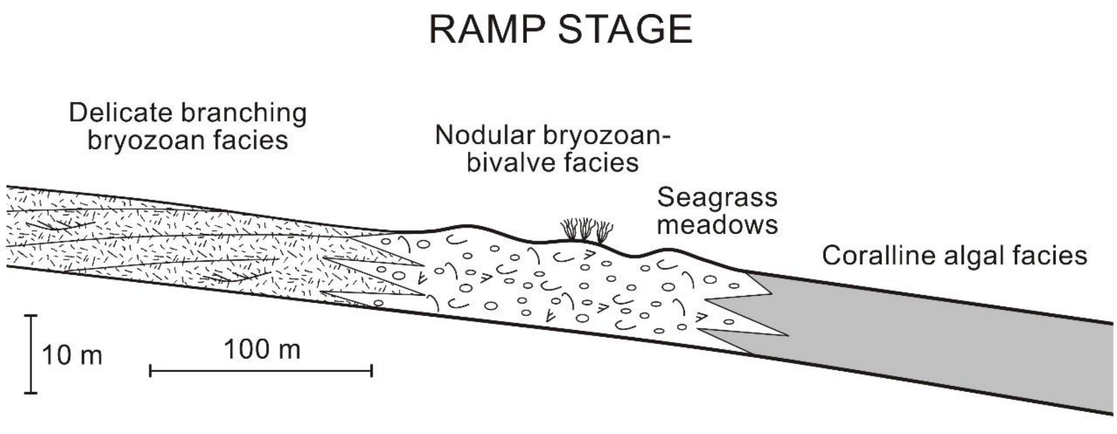


Figure 26. The uppermost temperate-carbonate units at Ricardillo (units 3B and 4) fossilized the small depressions. The sedimentary model is now that of a carbonate ramp dipping north (from Betzler et al. 2000).

Photograph 132.- The El Ricardillo is a volcanic dome generated during the first episode of vulcanism in Cabo de Gata. The volcanic rocks are flanked by temperate carbonates from the Tortonian-Messinian transition (Cabo de Gata. Cortijo del Ricardillo).

Photograph 133.- The volcanic rocks display columnar jointing (Cabo de Gata. Ricardillo).

Photograph 134.- The carbonate sequence consits of several, superimposed units (a, b, c y d). The lower ones infill a shallow, small depression (Cabo de Gata. Ricardillo). →

Photograph 135.- Sediments from the lower units inside the depression are red in colour. These sediments appear cross-cut by synsedimentary fractures (neptunian dykes) (dn) exhibiting a grey, bioclastic –rich marine infilling, with the same composition as the sediment from the immediately overlying units (Cabo de Gata. Ricardillo).

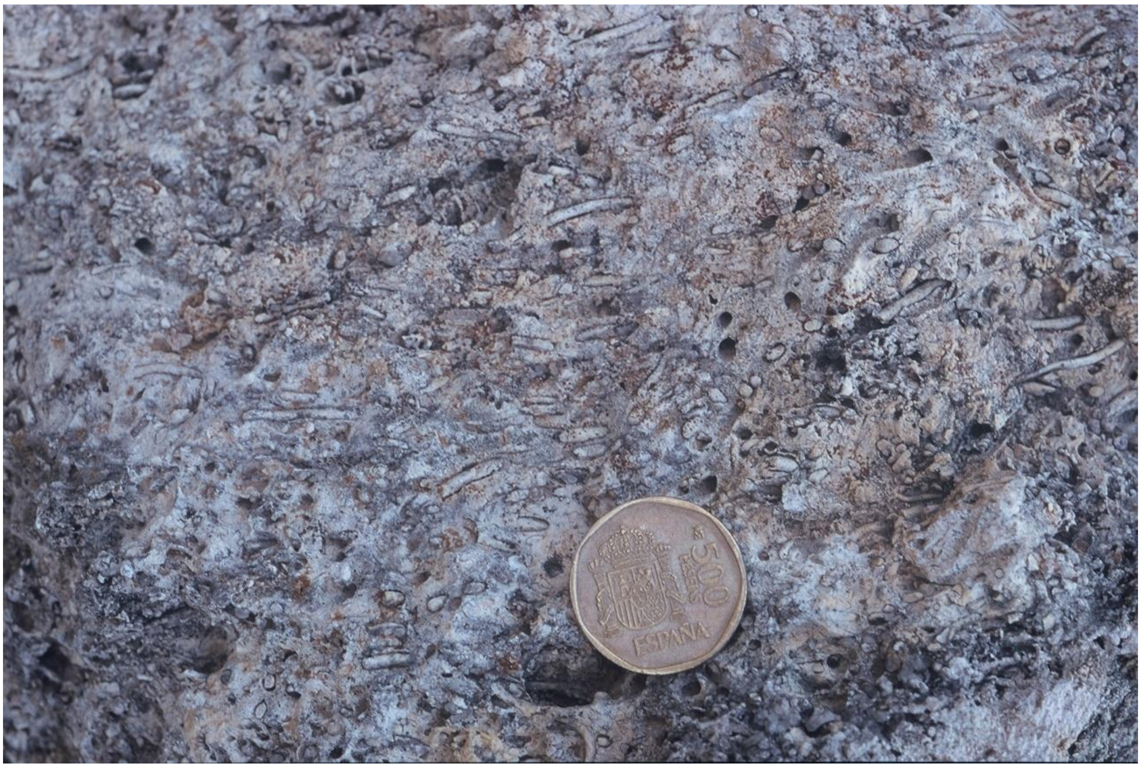
Photograph 136.- Large bryozoan remains abound in the infilling of the neptunian dykes (Cabo de Gata. Ricardillo).

Photograph 137.- Large barnacle skeletons appear in the infilling of the small depression (Cabo de Gata. Ricardillo).

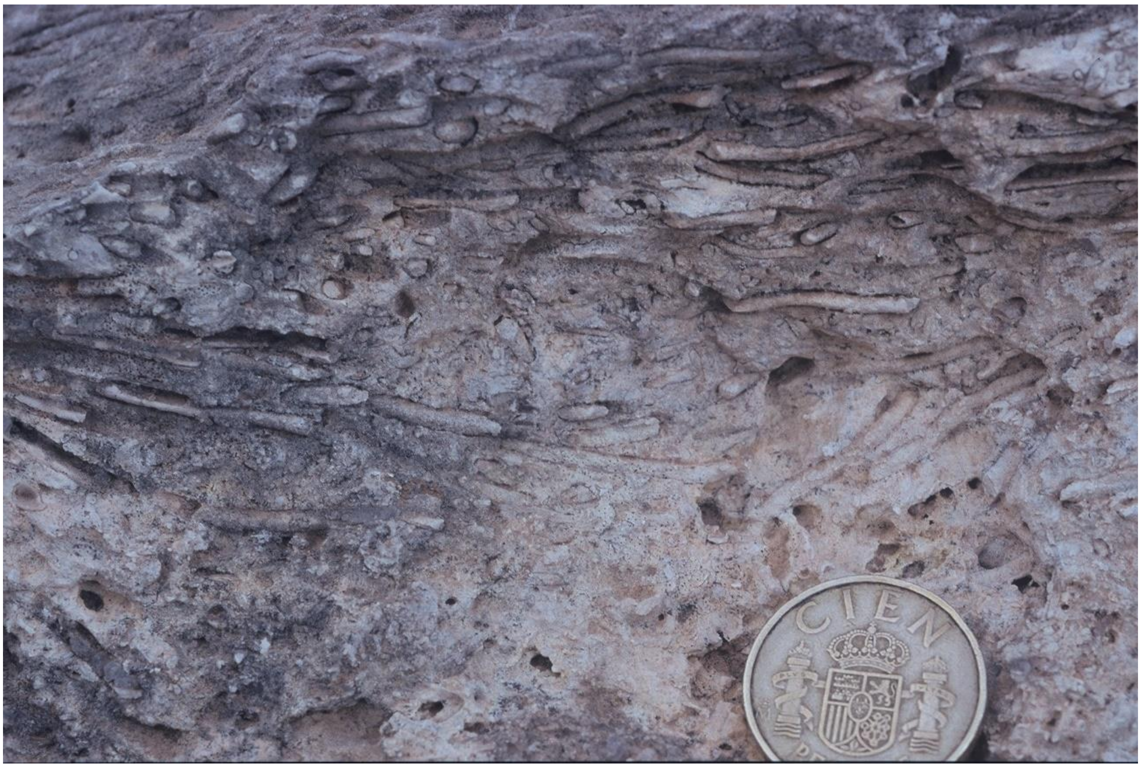
Photograph 138.- Barnacles concentrate in places forming small pavements (Cabo de Gata. Ricardillo).

Photograph 139.- Sediments are in direct, lateral contact with the volcanic rock at the depression margins. A vermetid buildup (V) developed at the western margin of the palaeodepression, attached to the wall of a former submarine cliff (Cabo de Gata. Ricardillo).

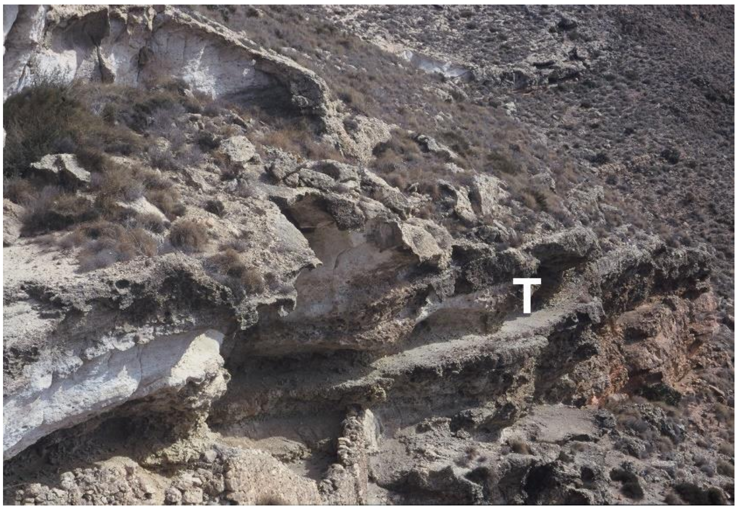
Photograph 140.- The vermetid tubes are preserved *in situ* (in growth position) and appear orientated perpendicularly to the volcanic rocks of the submarine palaeocliff (Cabo de Gata. Ricardillo).



Photograph 141.- Vermetid growth continued in the same way to the interior of the small, sedimentary depression (Cabo de Gata. Ricardillo).



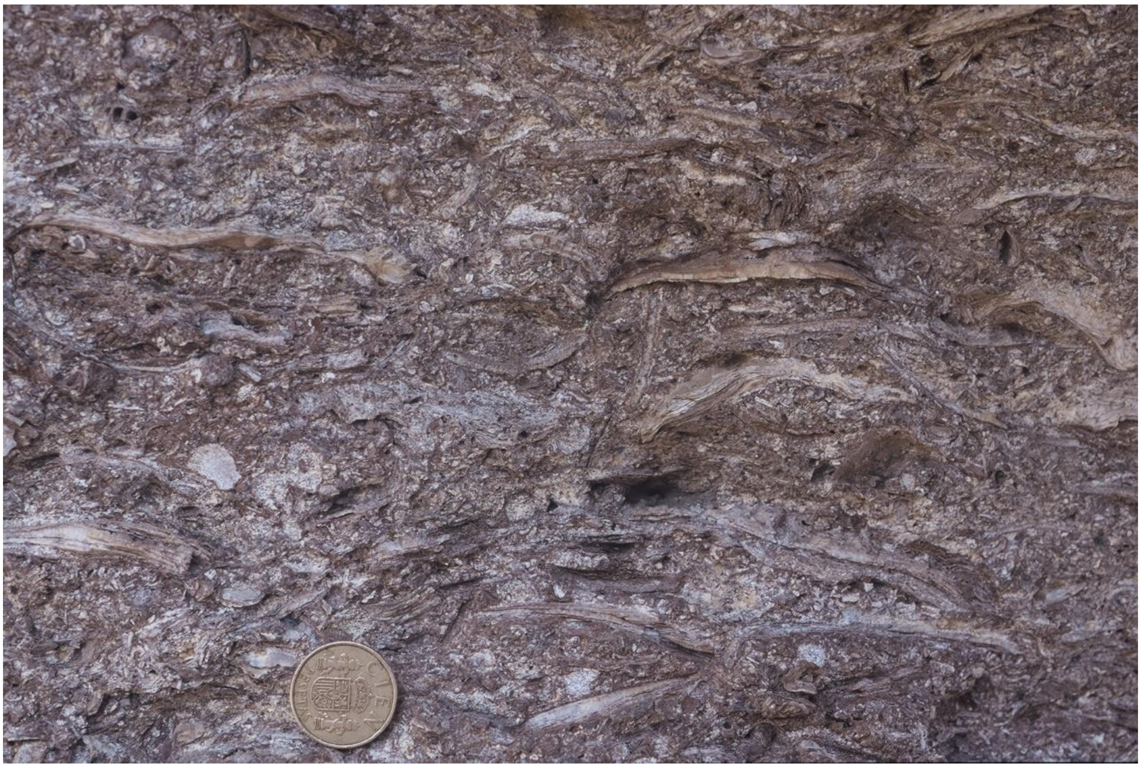
Photograph 142.- Only the internal moulds of the vermetid gastropods are now preserved and nothing remains of their original shell (it was dissolved) (Cabo de Gata. Ricardillo).



Photograph 143.- In some other locations, large, branching bryozoans lived directly attached to the walls of the submarine palaeocliff and their remains accumulated on the flanks of the sedimentary depression. The resulting talus deposits (T) (grey in colour) prograde to the interior of the small depression (Cabo de Gata. Ricardillo).

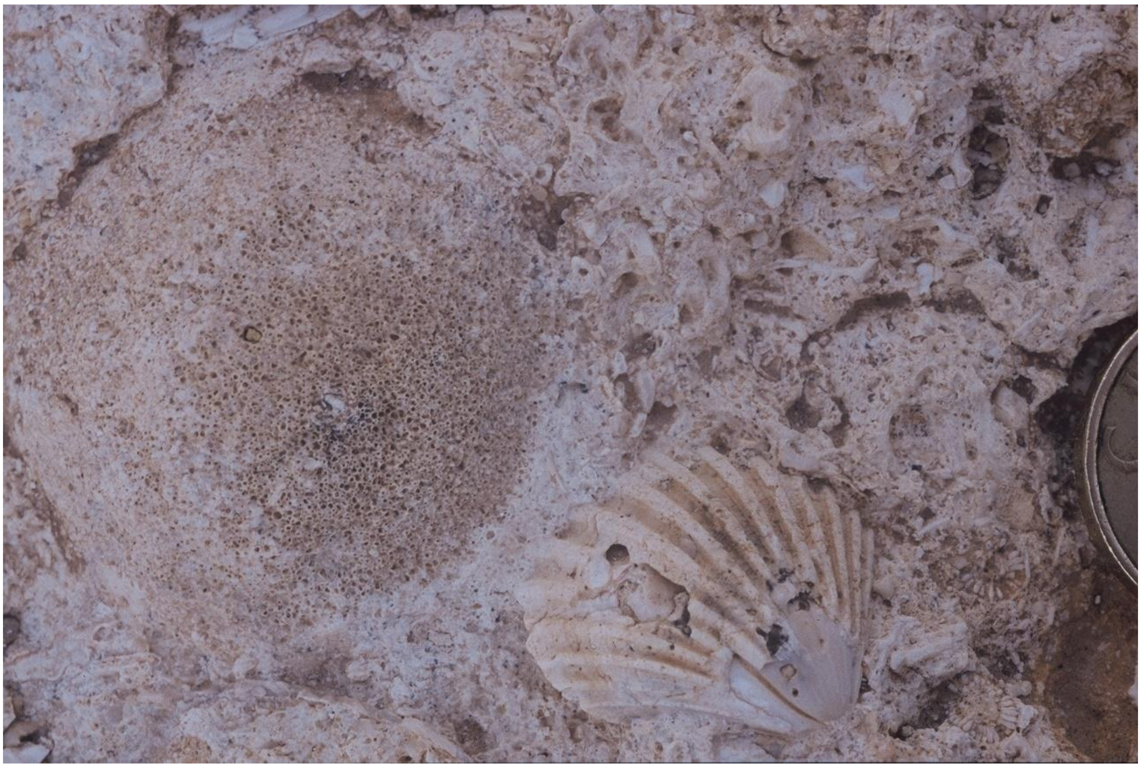
Photograph 144.- Field aspect of the branching bryozoan facies (Cabo de Gata. Ricardillo).

Photograph 145.- Some very large nodular bryozoans also appear locally (Cabo de Gata. Ricardillo).



Photograph 146.- Well-preserved *Isognomum* remains occur as well at the depression margins in places (Cabo de Gata. Ricardillo).

← Photograph 147.- The bottom part of the uppermost unit consists of a coastal conglomerate with abundant, and relatively well-rounded, volcanic-rock clasts embedded in a bioclastic-calcarenite matrix (Cabo de Gata. Ricardillo).



Photograph 148.- Well-preserved, large nodular bryozoan and pectinid remains abound in the factory facies of the upper ramp (Cabo de Gata. Ricardillo).

The Messinian reef units

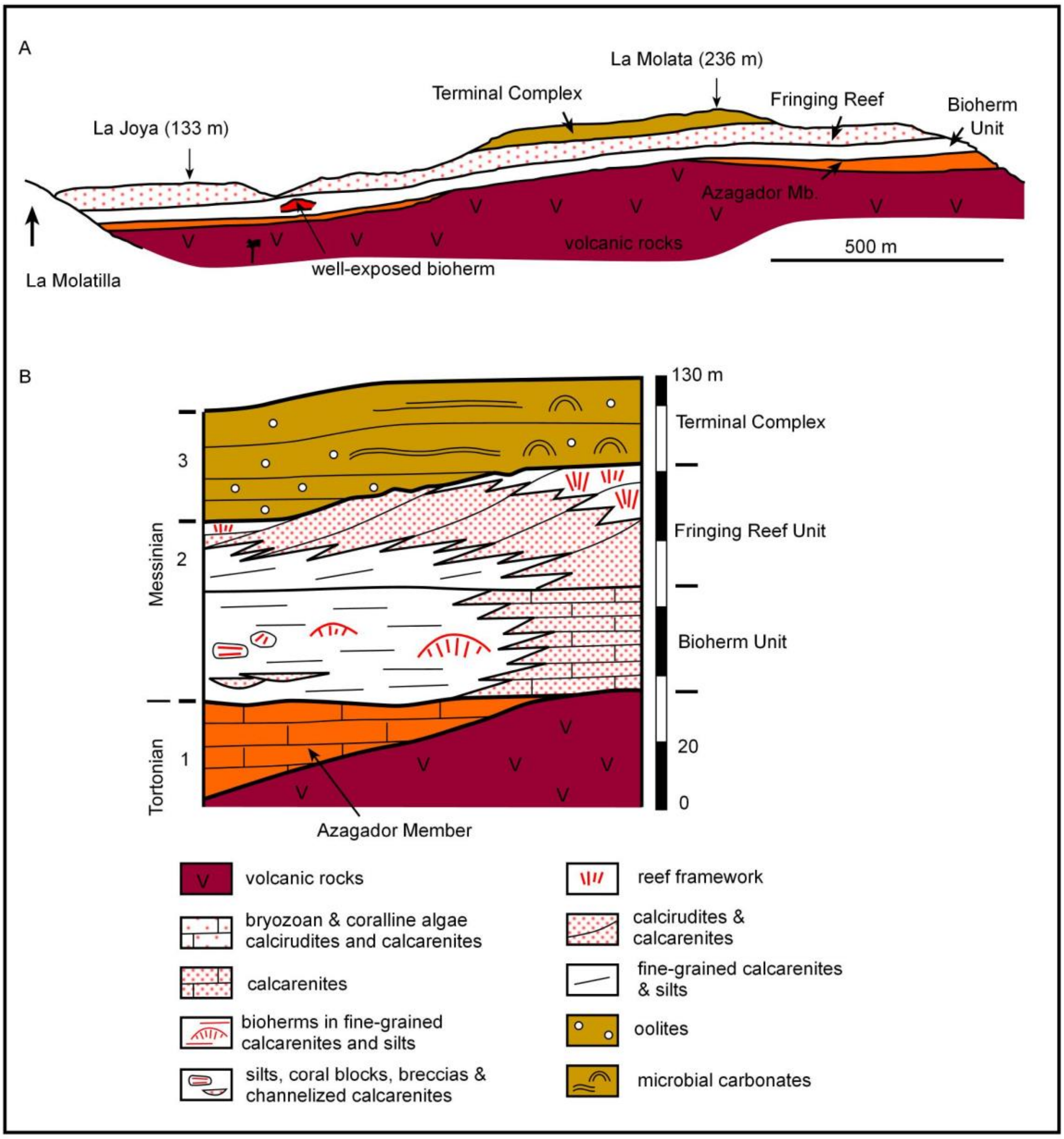
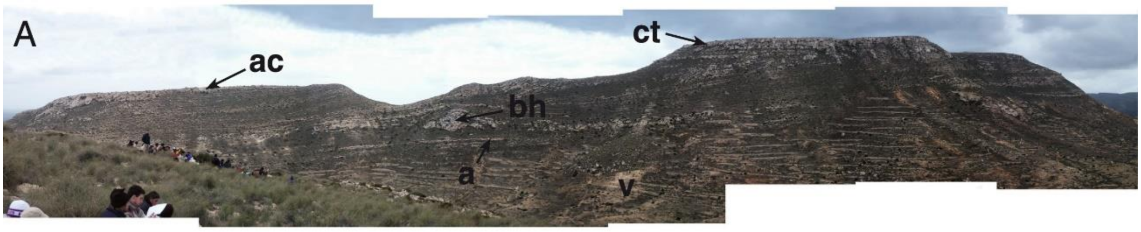


Figure 27. Cross-section and stratigraphic column of La Molata in the eastern Cabo de Gata (after Martín et al. 2003).

Photograph 149.- A: General view of the La Molata outcrop (v: Volcanic rocks; a: Azagador Member temperate carbonates from the Tortonian-Messinian transition; bh: Messinian coral bioherm; ac: Messinian fringing reef; ct: Uppermost Messinian Terminal Complex/Sorbas Member carbonates. B: Messinian coral bioherm standing out in the landscape (Cabo de Gata. Rambla del Cuervo. Las Negras). →



The Bioherm unit

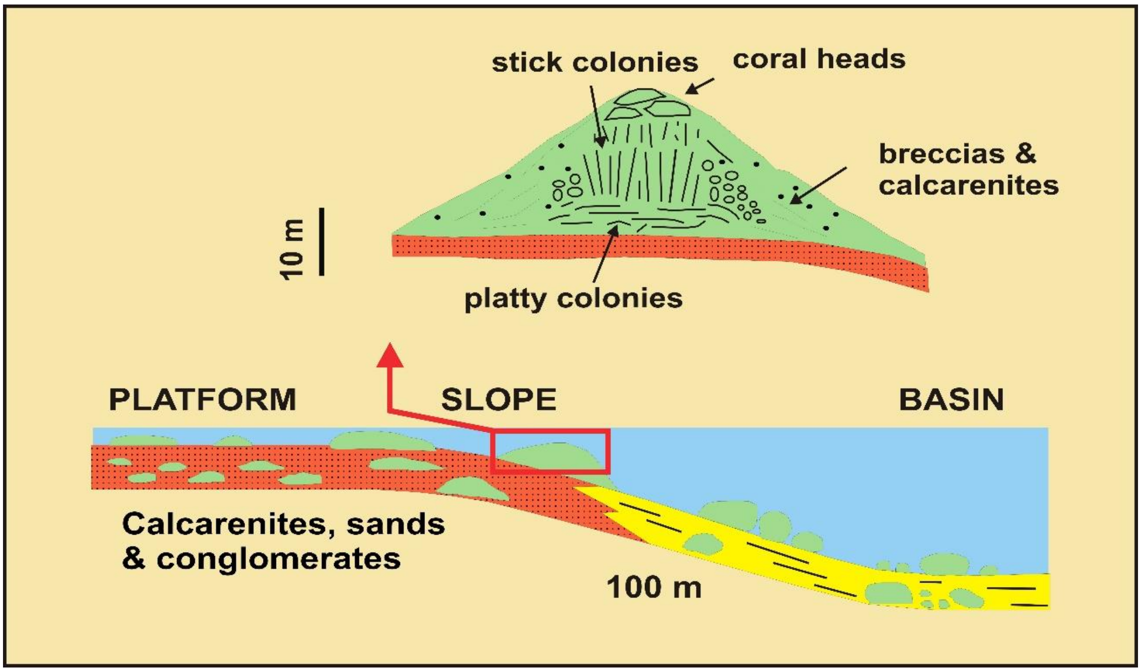
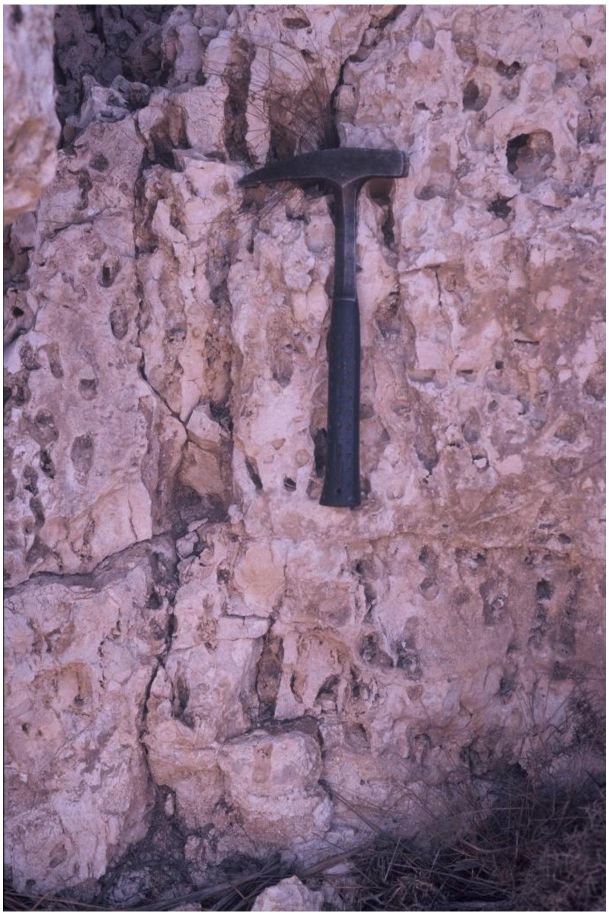


Figure 28. Schematic diagram of the typical constructional morphology of Messinian coral mounds (bioherms) (after Esteban et al. 1996), and sedimentary model (after Martín and Braga, 2010). Coral-bioherm fallen blocks intercalate within fine-grained slope and basinal sediments.

Photograph 150.- Laminar *Tarbellastraea* colonies piled one on top other from the lower part of the coral bioherm (Cabo de Gata. Rambla del Cuervo. Las Negras).

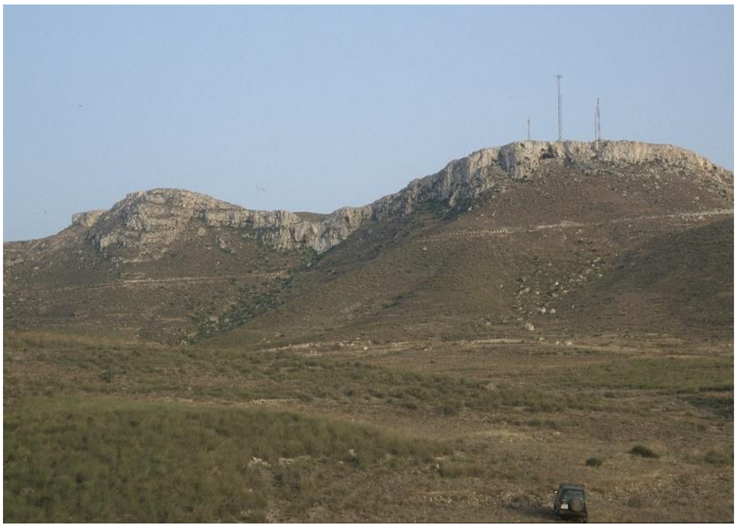
Photograph 151.- Close view of a laminar *Tarbellastraea*. The coral skeleton was locally bored by *Litophaga* (Cabo de Gata. Rambla del Cuervo. Las Negras).



Photograph 152.- Branching *Porites* colony from the middle part of the coral bioherm in the shape of long and thin, vertically-arranged sticks (Cabo de Gata. Rambla del Cuervo. Las Negras).

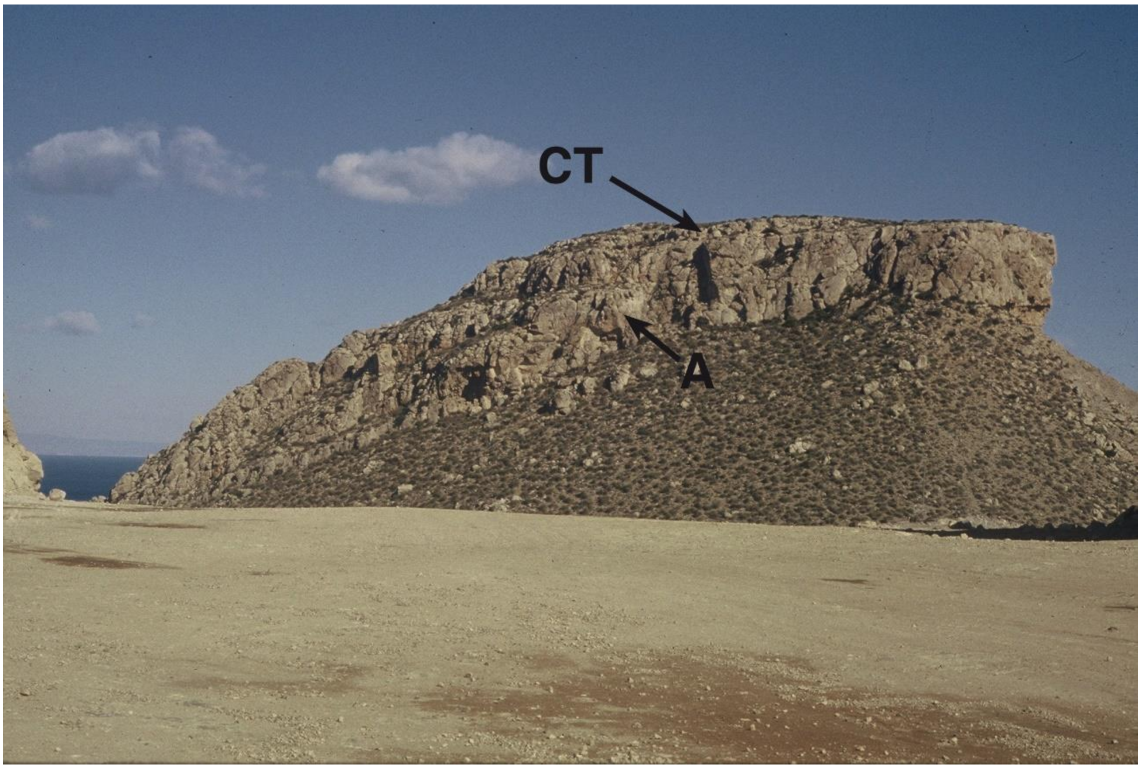
Photograph 153.- Hemispherical *Tarbellastraea* colony (*Tarbellastraea* “coral head”) from the upper part of the coral bioherm, seen in a vertical section (Cabo de Gata. Rambla del Cuervo. Las Negras).

The fringing-reef unit



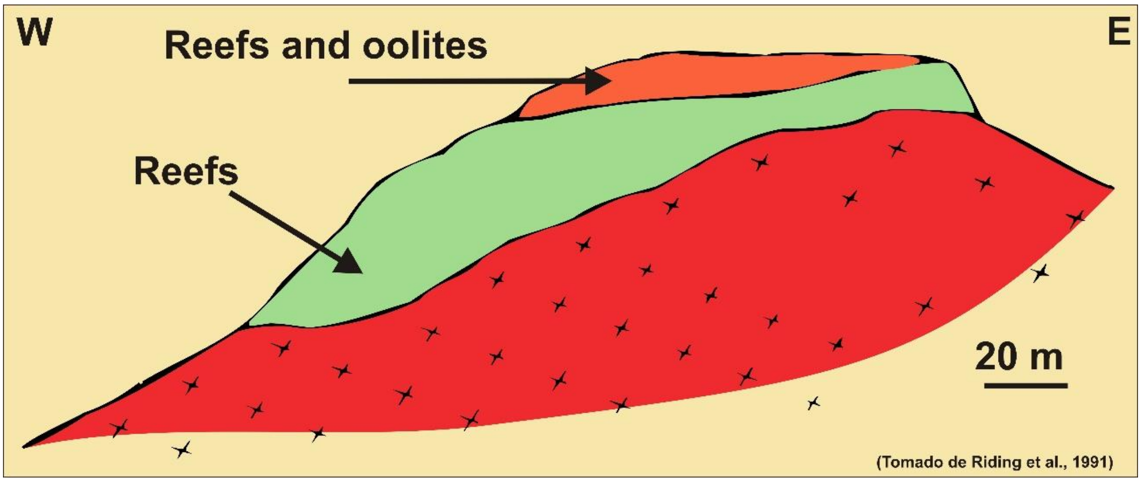
Photograph 154.- Messinian reefs fringing the volcanic relief of Mesa Roldán (La Chumbera).

The uppermost Messinian carbonates



Photograph 155.- Terminal Complex carbonates (CT) unconformably overlying Messinian reefs (A) (Mesa de Roldán).

Figure 29. (a): Geological sketch of Mesa de Roldán. Tortonian volcanics (lower and middle slope) are overlain by Messinian carbonates (after Riding et al. 1991). →



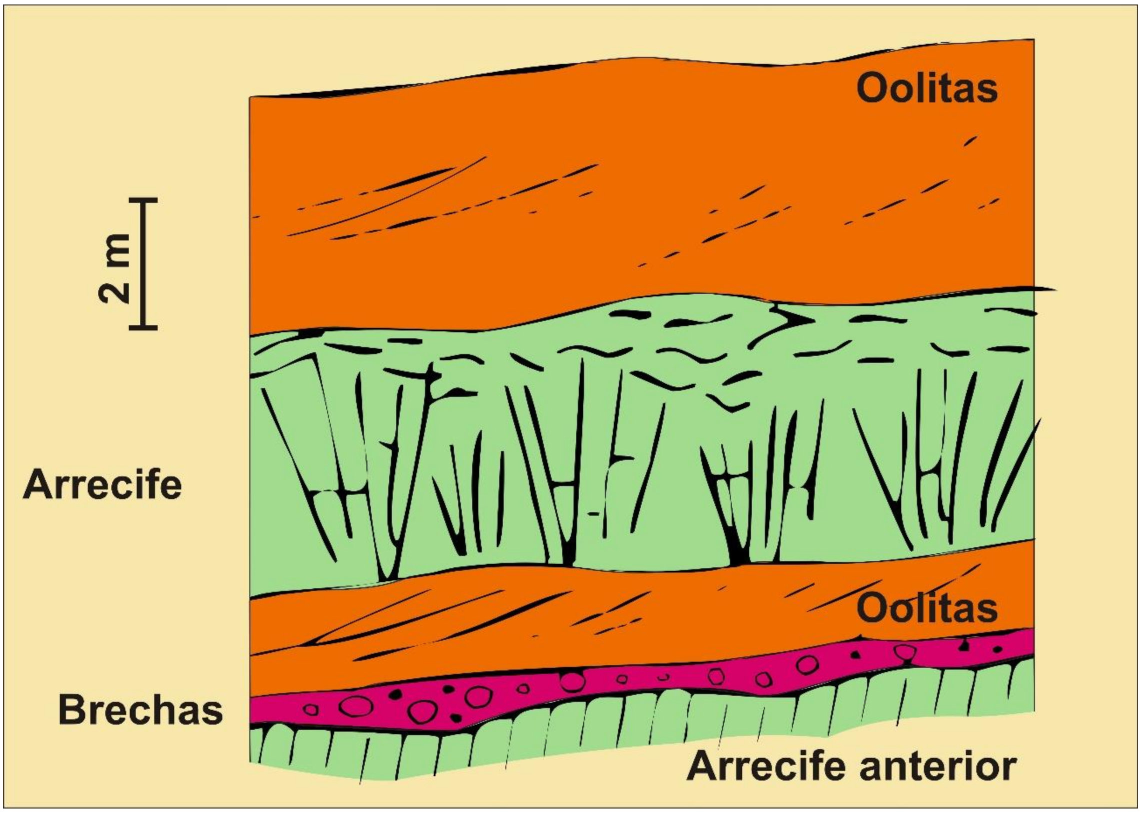
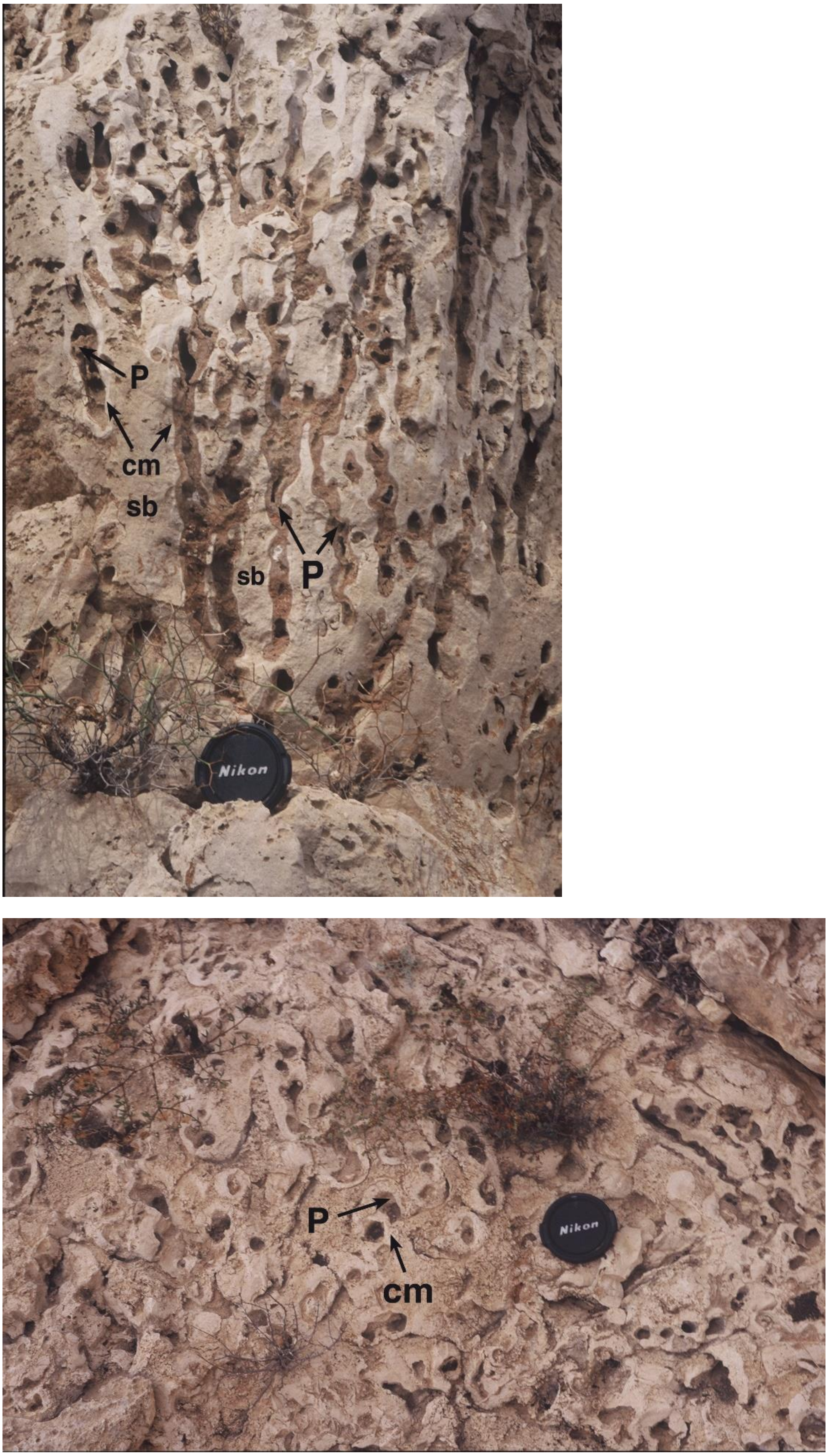


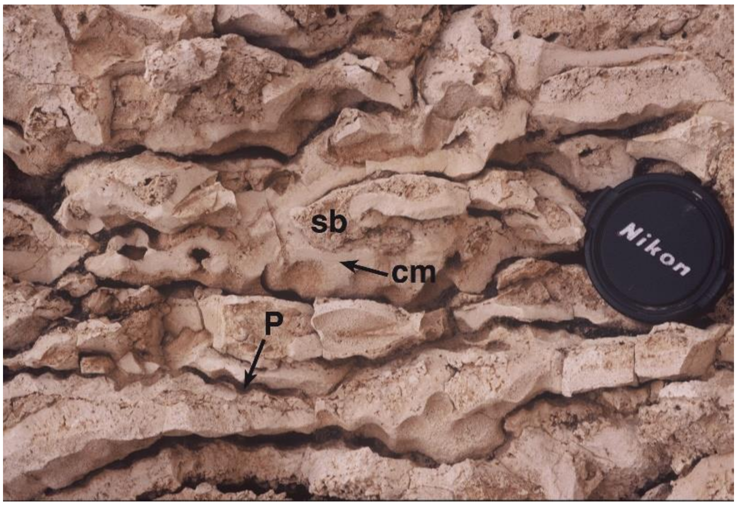
Figure 29. (b): Detailed section of the topmost carbonates with a small Porites patch-reef intercalated within oolitic limestones (after Riding et al. 1991).

Photograph 156.- Vertical section of a stick-like *Porites* colony from the base of a small patch-reef intercalated within the Terminal Complex oolites. The coral skeleton (P) is heavily leached and carstified. Thin, stromatolitic micrite crusts (cm) coat the coral skeleton. Lithified, bioclastic internal sediment (sb) infills the remaining voids in the bioconstruction (Mesa de Roldán). →



Photograph 157.- Micrite crusts (cm) around *Porites* tubes (P) stand out in plan-view sections (Mesa de Roldán).

Photograph 158.- The upper part of the bioconstruction shows subhorizontal, thin laminar *Porites* growths, together with thick micrite crusts and “pockets” of coarse-grained, bioclastic sediments (Mesa de Roldán).



Photograph 159.- Close view of the upper part of the coral patch-reef showing very clearly its three components: the laminar *Porites* growths (P), the micrite crusts (cm) and the internal, bioclastic sediment (sb) (Mesa de Roldán).

The Pliocene temperate carbonates of the Carboneras basin and nearby areas

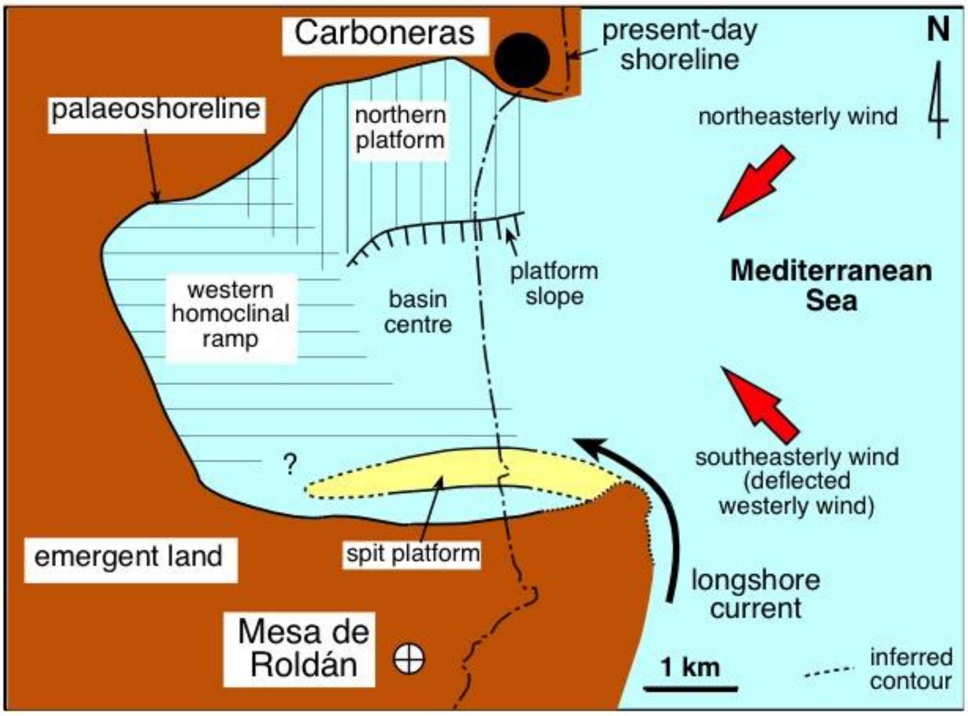
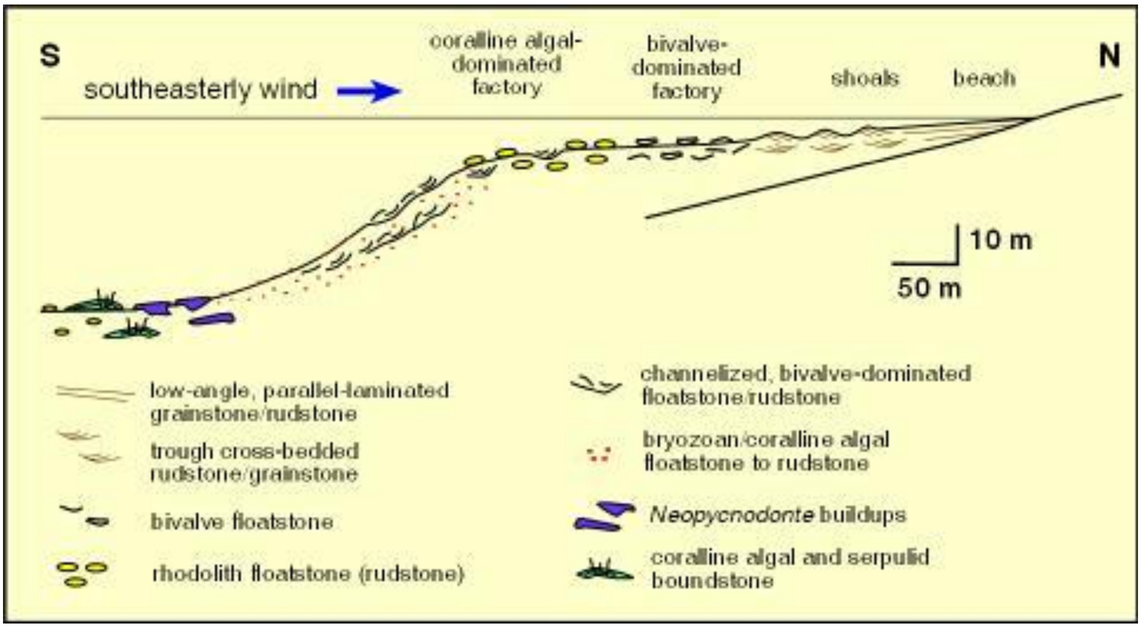


Figure 30. Paleoenvironmental reconstruction of the Carboneras embayment. At the northern margin a prograding carbonate platform developed. At the southern margin longshore currents, driven by the southeasterly winds, accumulated carbonate sands and gravel in the shelter of a protruding cape and built a spit-platform. The embayment interior (western margin) was a sheltered, low-energy, carbonate-ramp environment with a gentle, bottom-profile relief. White arrows indicate prevailing wind directions for the present-day eastern coast of Almería in SE Spain (after Martín et al. 2004; modified from Braga et al. 2003).

Figure 31. (a): Depositional model for the northern margin of the Carboneras embayment during the Early Pliocene. A narrow carbonate platform with a frontal steep slope developed there. Bivalves extensively colonized outer-platform settings, seaward of carbonate shoals. A rhodolith pavement covered the platform-edge area. Storm-mobilized bioclastic sediments were removed from the platform and redeposited on the slope. At the toe of the slope, coralline build-ups, rhodolith pavements and small *Neopycnodonte* patches formed. (after Martín et al. 2004). →



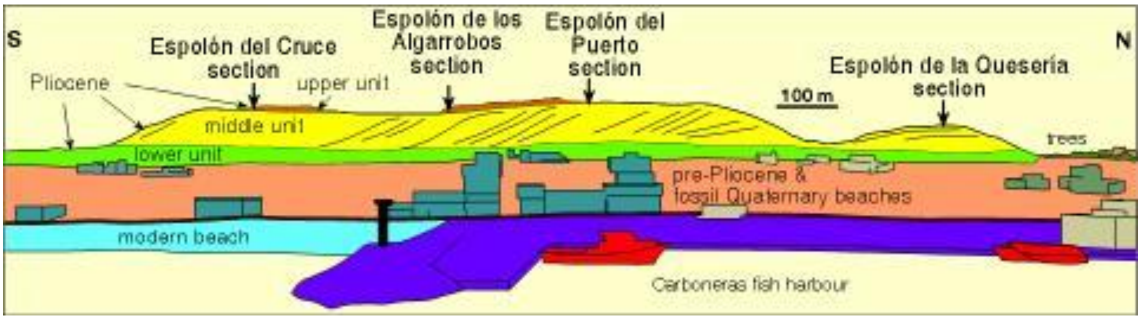


Figure 31 (b): The northern transect, at the Loma del Pinico from the Carboneras Harbour. Pliocene carbonates unconformably overlie Messinian marls-carbonates and Tortonian volcanic rocks, and can be subdivided into three units. The middle unit, which is also the thickest, exhibits SSW-dipping carbonate strata prograding to the south (after Martín et al. 2004).

Photograph 160.- Pliocene carbonates from the northern margin of the Carboneras Basin (Carboneras. Loma del Pinico view from the Carboneras fishing-harbour). →

Photograph 161.- Detail of the panoramic view showing the different systems-tracts deposits of the Pliocene carbonate unit; the lowstand systems-tract deposits (l), the transgressive systems-tract deposits (t) and the highstand systems-tract deposits (h). Transgressive systems-tract deposits deep significantly to the South, while the two others (lowstand and highstand deposits) are horizontal or subhorizontal (Carboneras. Loma del Pinico view from the Carboneras fishing-harbour).

Photograph 162.- Factory facies from the inner ramp/inner platform with abundant, well-preserved pectinid remains (Carboneras. Loma del Pinico).

Photograph 163.- Factory facies from the inner ramp/inner platform with abundant, well-preserved oyster remains (Carboneras. Loma del Pinico).

Photograph 164.- Rhodolith pavement developed at the platform edge (Carboneras. Loma del Pinico).

Photograph 165.- Tempestite bed with abundant oyster fragments intercalated with fine-grained calcarenite from the platform-slope (Carboneras. Loma del Pinico).

The gentle ramp inside the Carboneras embayment

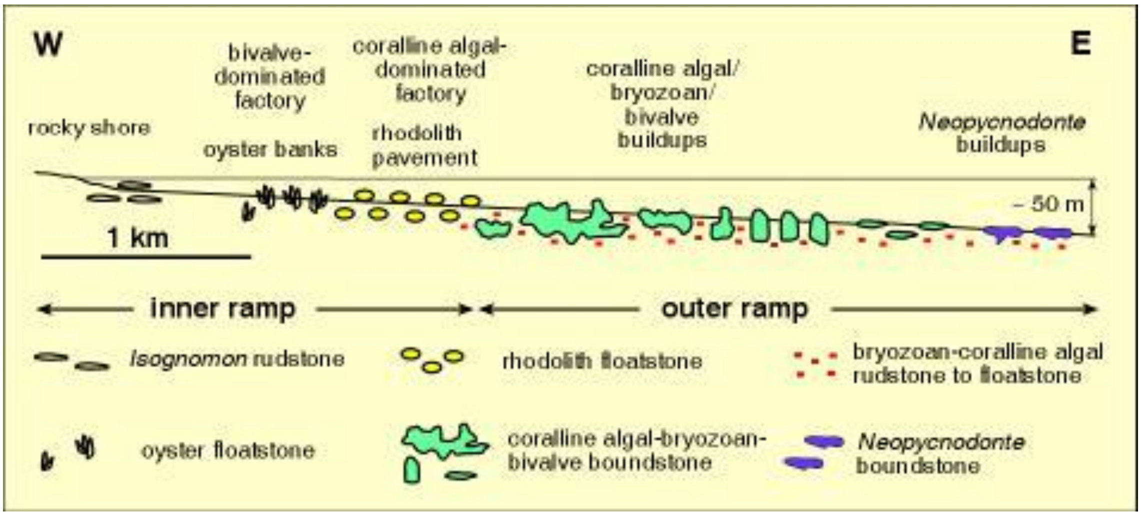
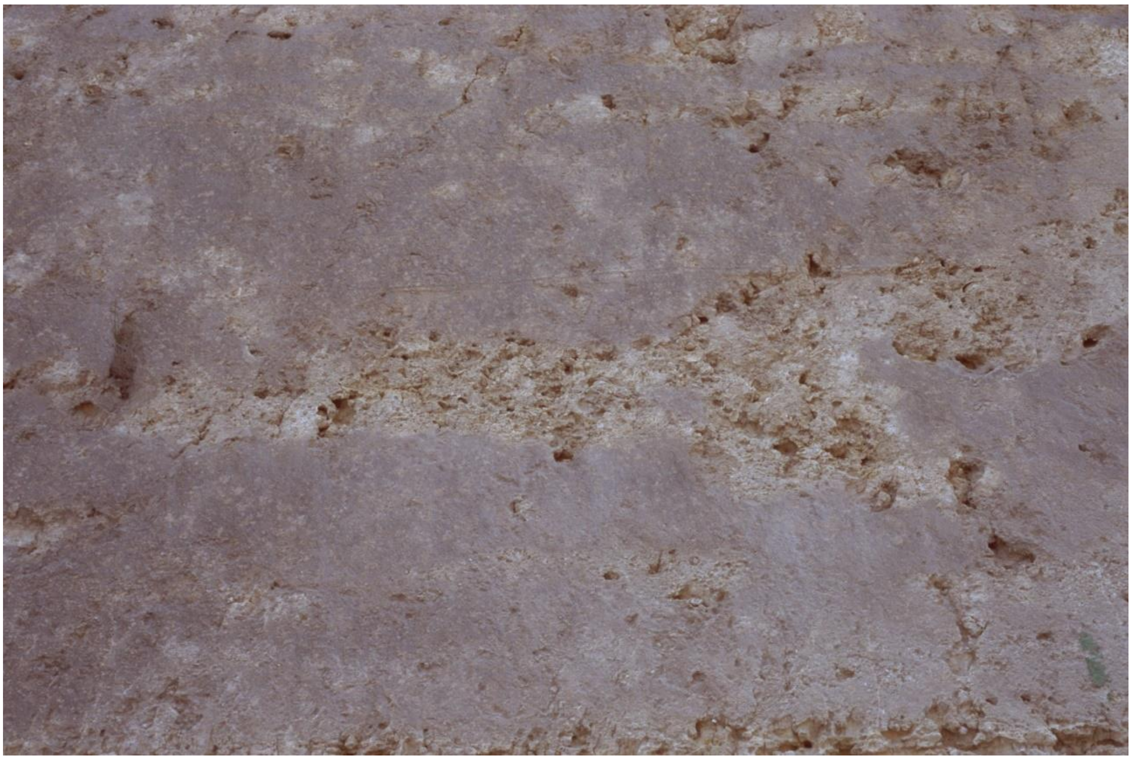


Figure 32. Depositional model for the western, Carboneras-embayment interior during the Early Pliocene. A variety of bioconstructions developed at different depths within the gentle ramp: *Isognomon* accumulations occurred at the coast, oyster banks and rhodolith pavements in the inner ramp, and coralline algal-bryozoan-bivalve build-ups and *Neopycnodonte* patches in the outer ramp (after Martín et al. 2004).

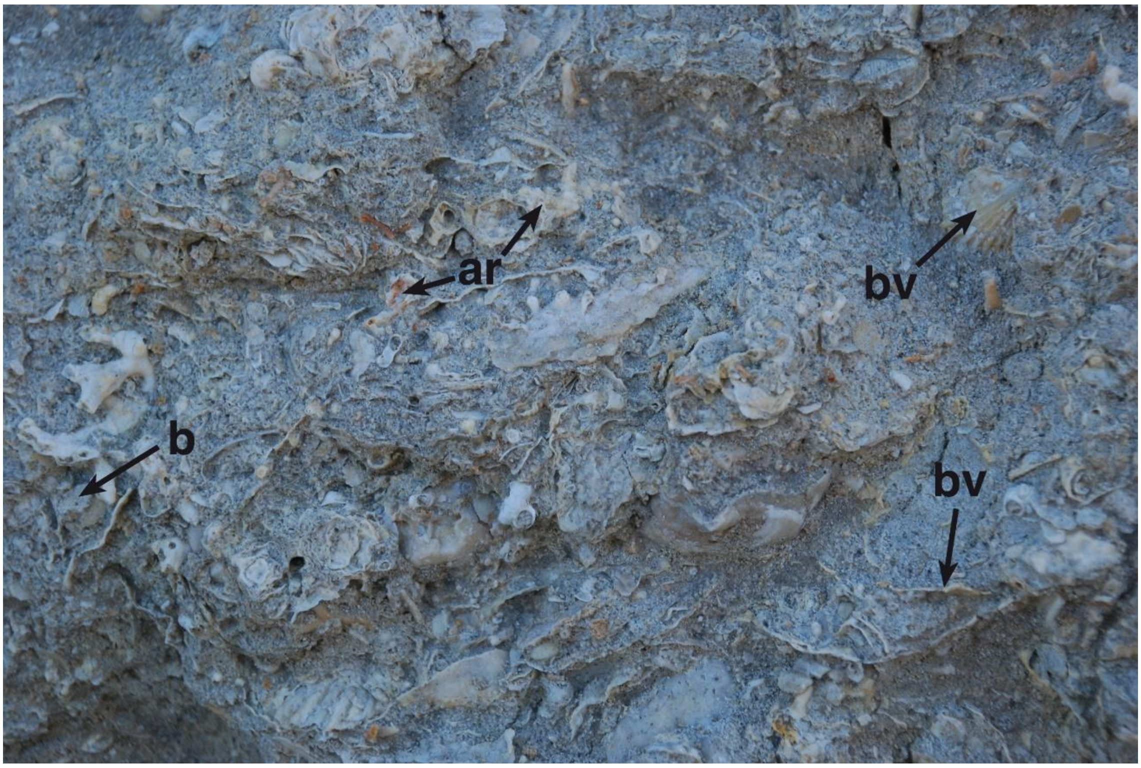
Photograph 166.- Plan view of an oyster biostrome from the innermost embayment zone (Carboneras. Las Covaticas).



Photograph 167.- Coralline-algal, bryozoan, bivalve bioconstruction exhibiting a highly-irregular morphology. Outer embayment zone (Carboneras. Rellana de las Contraviesas).

Photograph 168.- Coralline-algal, bryozoan, bivalve bioconstructions in the shape of pillars or small pinnacles. Outer embayment zone (Carboneras. Rellana de las Contraviesas).

Photograph 169.- Close view of a coralline-algal, bryozoan, bivalve pillar (Carboneras. Rellana de las Contraviesas).



Photograph 170.- Coralline algal crusts (ar) are dominant in the bioconstructions. Branching and nodular bryozoan remains (b) stand out as well together with some, well-preserved bivalve shells (bv) (Carboneras. Rellana de las Contraviesas).

Photograph 171.- Close view of some bryozoan (branching and nodular) growths (Carboneras. Rellana de las Contraviesas).

Photograph 172.- Some, laminar fenestellid-bryozoan growth also occurs (Carboneras. Rellana de las Contraviesas).

Photograph 173.-A well-preserved *Spondylus spinosis* shell inside one of the bioconstructions (Carboneras. Rellana de las Contraviesas).

The southern spit

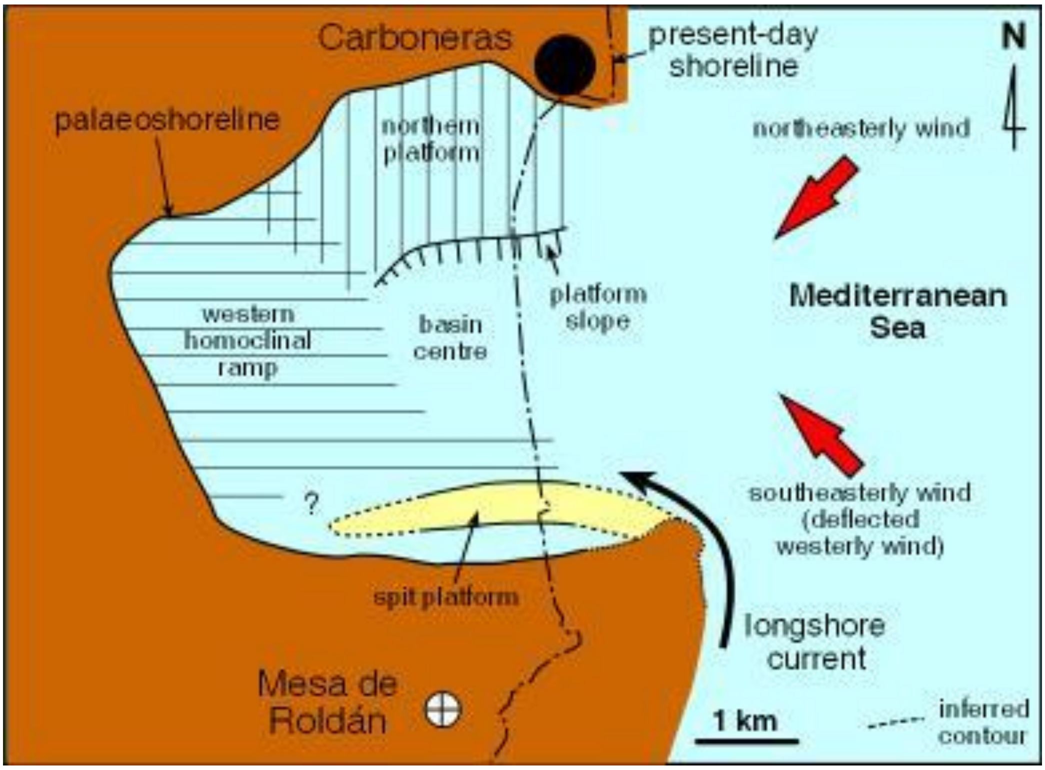


Figure 33. A. Early Pliocene depositional model for the southern margin of the Carboneras embayment (after Martín et al. 2004).

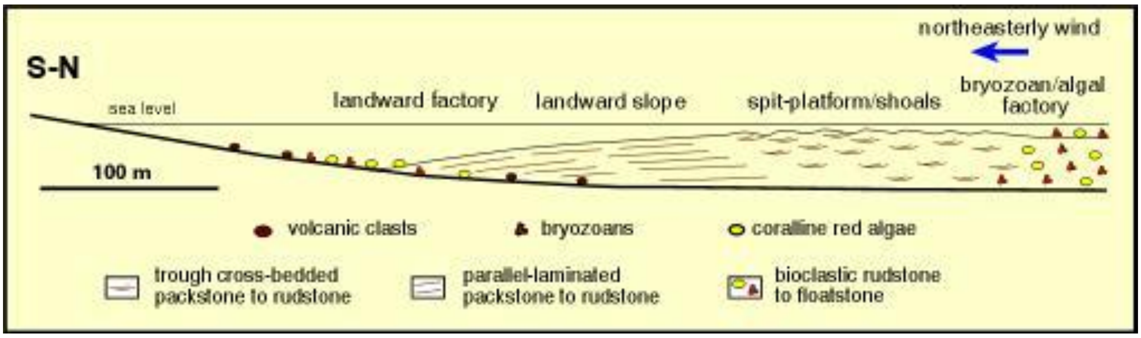


Figure 33. B. At the southern margin, spit-platform deposits were accumulated by longshore currents several hundred metres away from the shoreline. Shoal deposits developed on top of and seaward of the spit-platform. A factory area occurred seaward of the shoals (after Martín et al. 2004).

Photograph 174.- Sediment layers gently dipping to the South (to the palaeoshore line) as result of the spit progradation (Carboneras. Playa de los Muertos).

Photograph 175.- Shoal facies, exhibiting a very evident cross bedding, intercalated with factory facies (Carboneras. Torre Vieja).

The washover fans

Photograph 176.- Highstand washover fan (storm) deposits prograding on top of lagoonal silts (Carboneras. Los Muertos).

Photograph 177.- Bivalve remains abound in the washover-fan layers. Because of early shell-leaching only their internal moulds are now preserved (Carboneras. Los Muertos).

Palaeocliff and shallow-depression facies

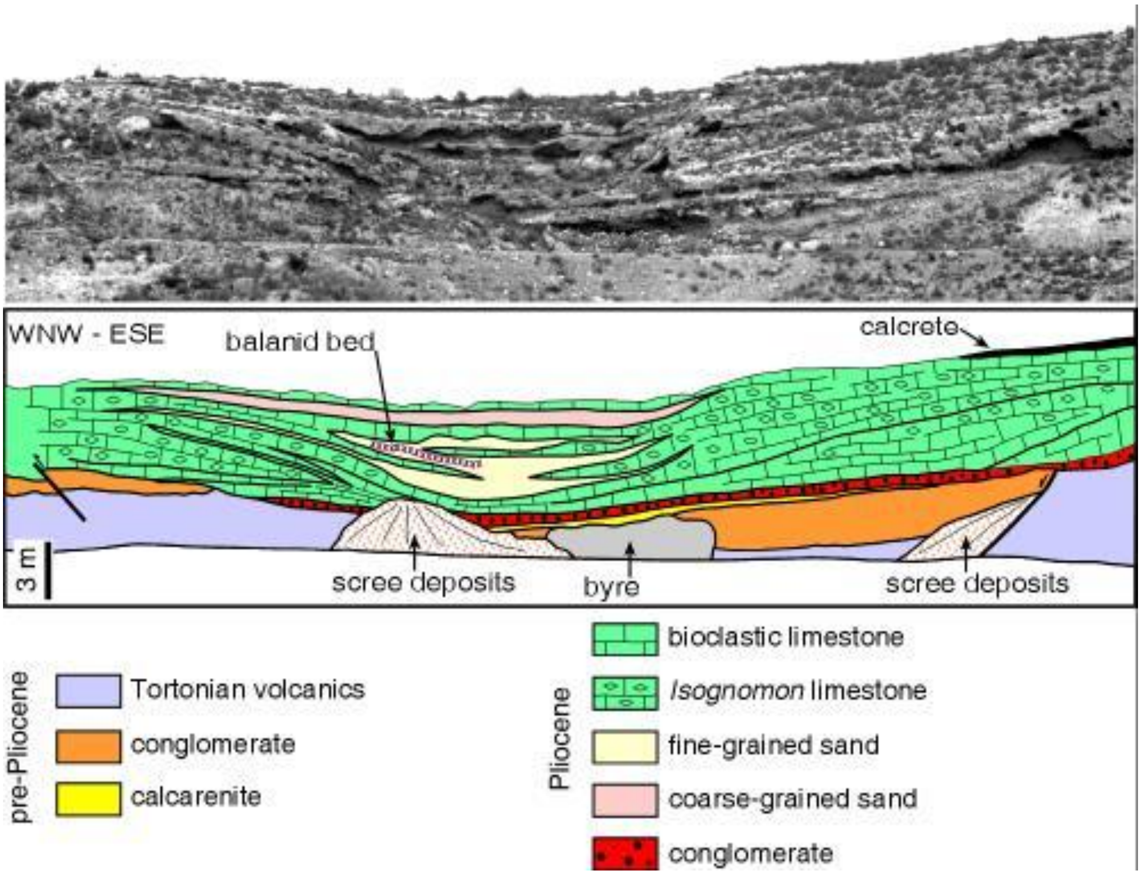


Figure 34. El Castillíco section represents the infill of a small sheltered shallow depression. *Isognomon* limestones were deposited in the margins and fine-grained sands in the centre. The stacking pattern shows aggradation and progradation of the *Isognomon* facies towards the centre of the depression. Barnacle-rich sediments ("balanid bed") appear in the top of the sand (after Aguirre et al. 2008).

Photograph 178.- General view showing the sedimentary infilling of a coastal, small depression. Sediment layers dip and prograde towards the depression interior from both margins (Carboneras. El Castillíco).

Photograph 179.- *Isognomum*-rich layer from the depression margin. Present-day erosion has removed some of the *Isognomum* internal moulds (Carboneras. El Castillíco).

Photograph 180.- Close view of the *Isognomum* facies (Carboneras. El Castillíco).

Photograph 181.- Barnacle accumulations (barnacle pavements) in calcarenite/bioclastic sands inside the small depression (Carboneras. El Castillíco).

Photograph 182.- Dispersed barnacle colonies within the calcarenite/bioclastic sands (Carboneras. El Castillíco).

Photograph 183.- Close view of a barnacle colony showing a partly-preserved basal plate (Carboneras. El Castillíco).

Barnacle bioconstructions related to channels and lobes of conglomeratic deltas

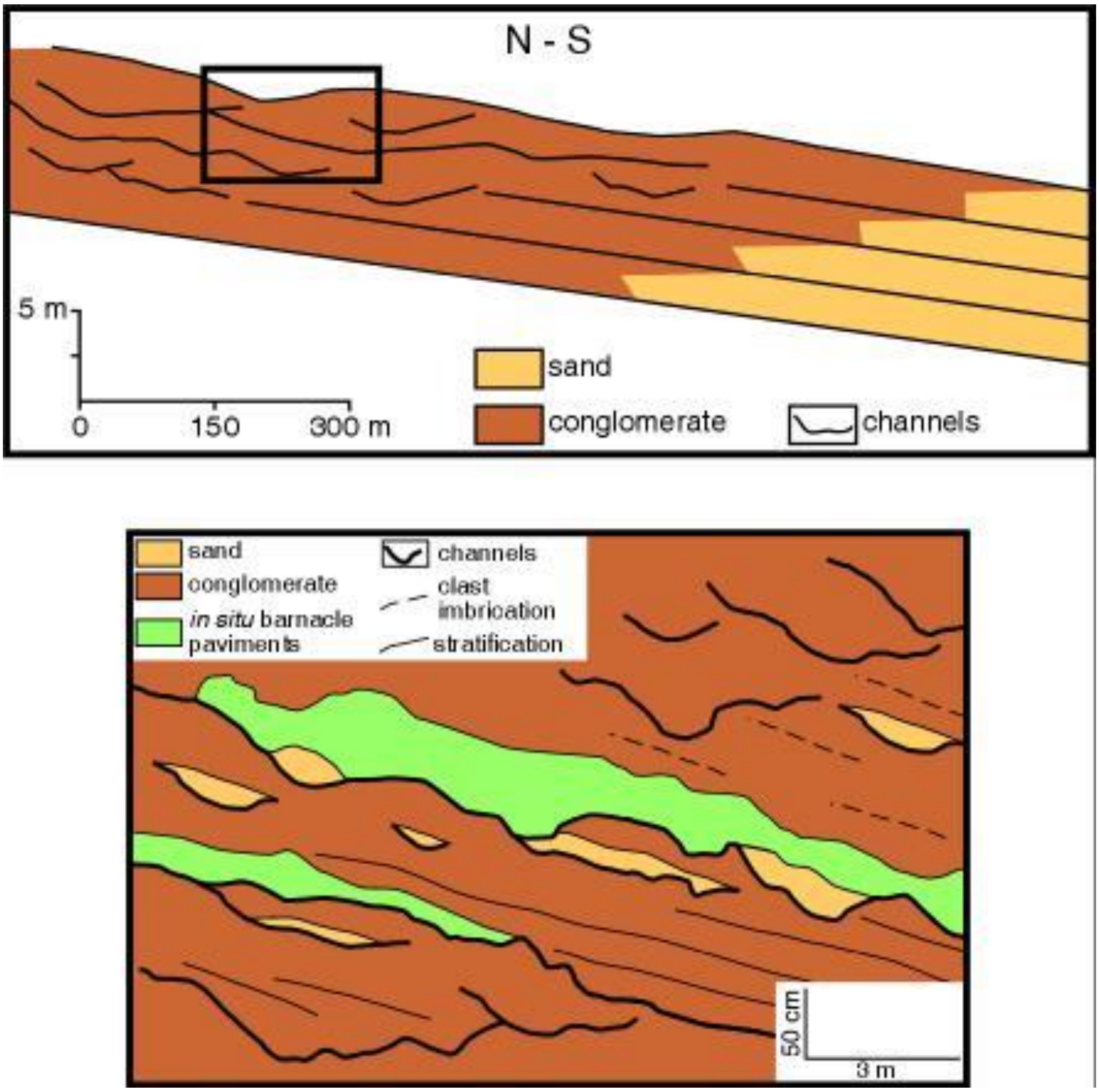
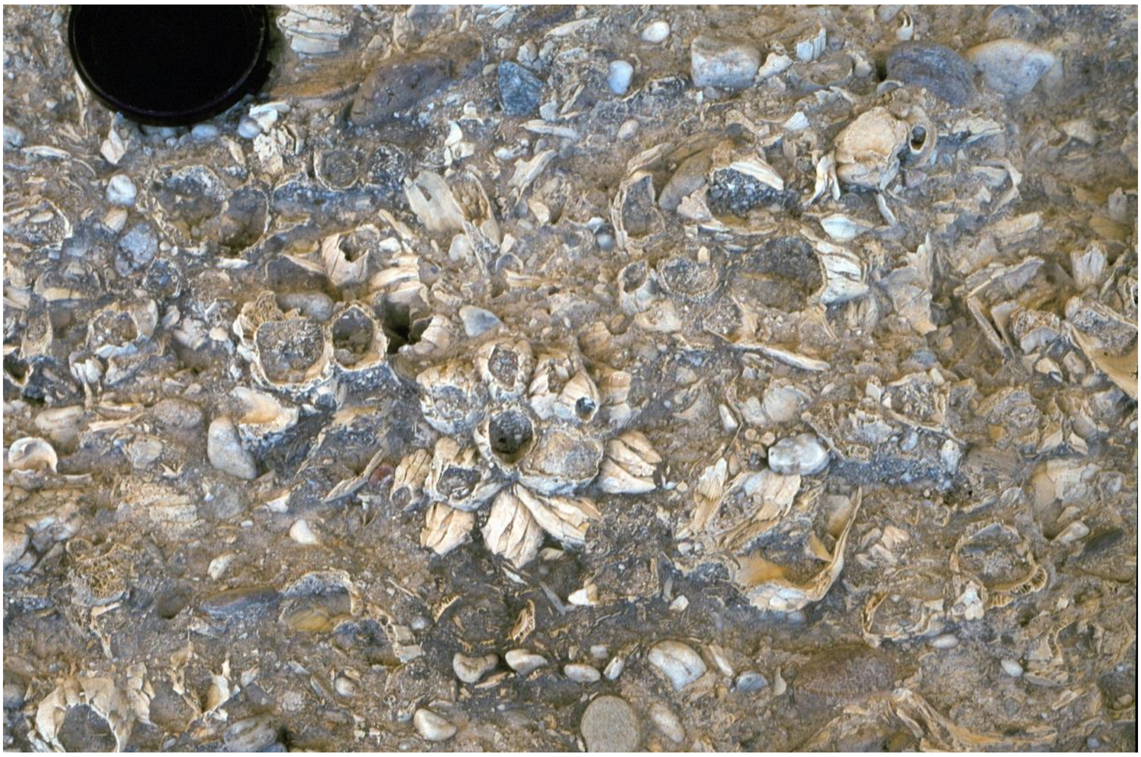


Figure 35. Vía del Tren section. General facies distribution pattern and detail scheme of the channelized area. Barnacle pavements are directly related to channels (after Aguirre et al. 2008).

Photograph 184.- Barnacle level intercalated within conglomerates (Carboneras. Las Covaticas).

Photograph 185.- Barnacle level intercalated within sands and conglomerates from the base of a channel (Carboneras. Trench of the former Lucainena-mine tram).

Photograph 186.- Barnacles on conglomerates (Carboneras. Trench of the former Lucainena-mine tram).



Photograph 187.- Plan-view of a barnacle pavement (Carboneras. Trench of the former Lucainena-mine tram).

Photograph 188.- Most of the barnacle colonies directly colonized conglomerate clasts (Carboneras. Trench of the former Lucainena-mine tram).

Photograph 189.- Fan-array barnacle colony on a quartz clast (Carboneras. Trench of the former Lucainena-mine tram).

Photograph 190.- Quartzite clast encrusted by a bryozoan colony (Carboneras. Trench of the former Lucainena-mine tram).

The large-scale (“giant”) dunes of the Río Alías Strait

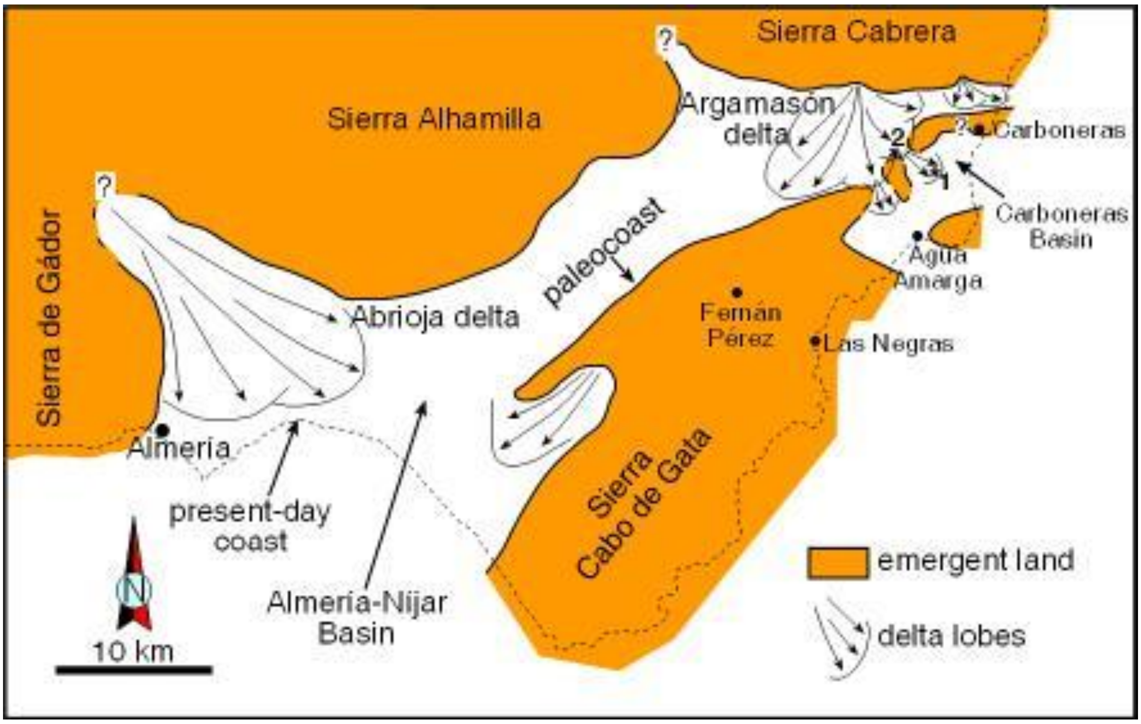


Figure 36. Palaeogeographic map of the Almería-Níjar and Carboneras basins during the Early Pliocene with indication of the position of the Río Alías Strait (modified from Aguirre et al. 2008).

Photograph 191.- Cross-bedding sets, up to 15 m high, pointing to the West from the entrance of the former Río Alías Strait (Carboneras. El Llano de don Antonio).

Photograph 192.- Trough cross bedding of minor scale linked to submarine-dune migration along the Río Alías Strait at its exit towards the Almería-Níjar Basin (Carboneras. El Argamasón).

Fossil Quaternary beaches and rocky shores

Photograph 193.- Eastwards-prograding, Quaternary-beach deposits on top of Pliocene fine-grained calcarenites. These fossil beach deposits are now placed 7-8 m above Present-day sea level (Carboneras).

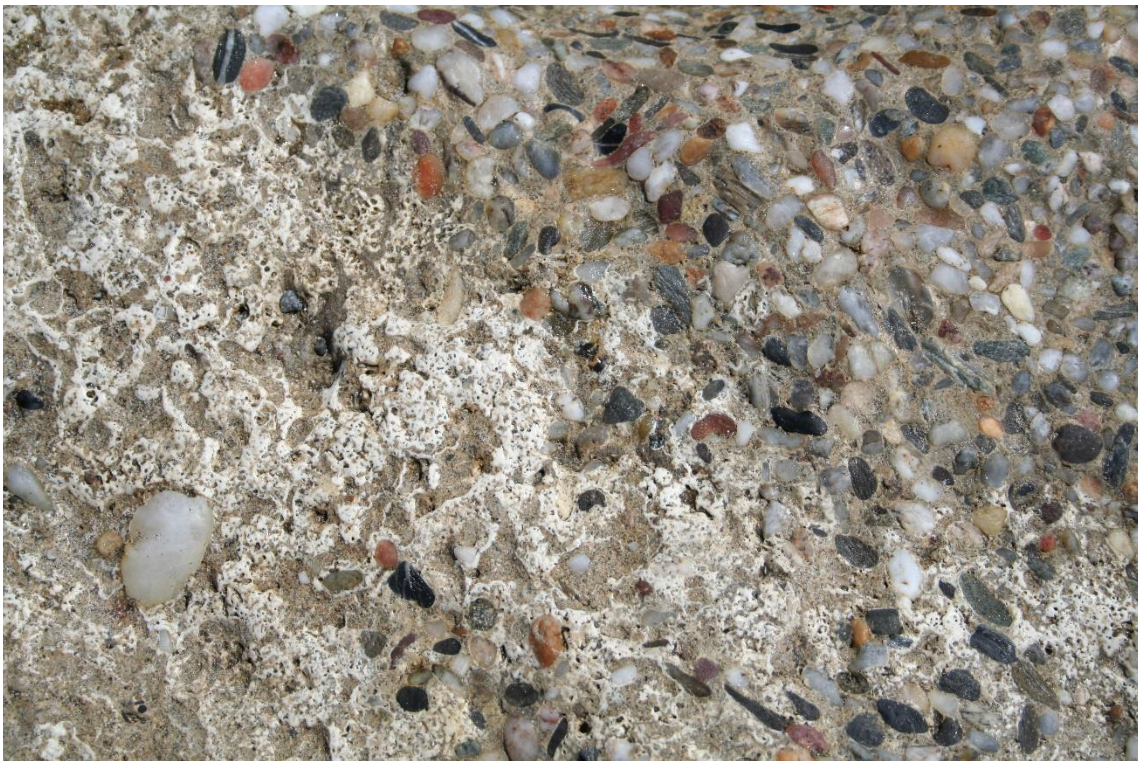
Photograph 194.- Low-angle, foreshore, parallel-lamination is the most obvious sedimentary structure from these beach deposits (Carboneras)

Photograph 195.- The sand-to-pebble sediment from the beach in the picture is artificially introduced at the beginning of the summer season (El Lacón beach in the early summer. Carboneras).

Photograph 196.- In the autumn/winter, eastern storms (“levante storms”) remove the artificially-introduced loose sands (pebbles) and uncovered, at the surface, the well-cemented, old-Quaternary coastal deposits. Some huge volcanic-rock blocks, delivered by present-day rivers (“ramblas”), are introduced at this time as well to the coast and temporaly abandonned on top of the old-Quaternary deposits (El Lacón beach in the winter. Carboneras).

Photograph 197.- Close view of the well-cemented, fossil, Quaternary beach deposits with some loose volcanic-rock blocks on top (Carboneras).

Photograph 198.- The cemented levels correspond to a rocky-shore deposit. The base of the deposit is an erosional surface, excavated into previous, well-cemented beach sediments, encrusted by coralline algae. These coastal red-algal encrustations are known as “trottoirs” (t). A cemented conglomerate, with abundant and well-rounded quartz clasts (c) and blocks from the underlying beach deposits (b), was deposited on top of the algal crusts (Carboneras).



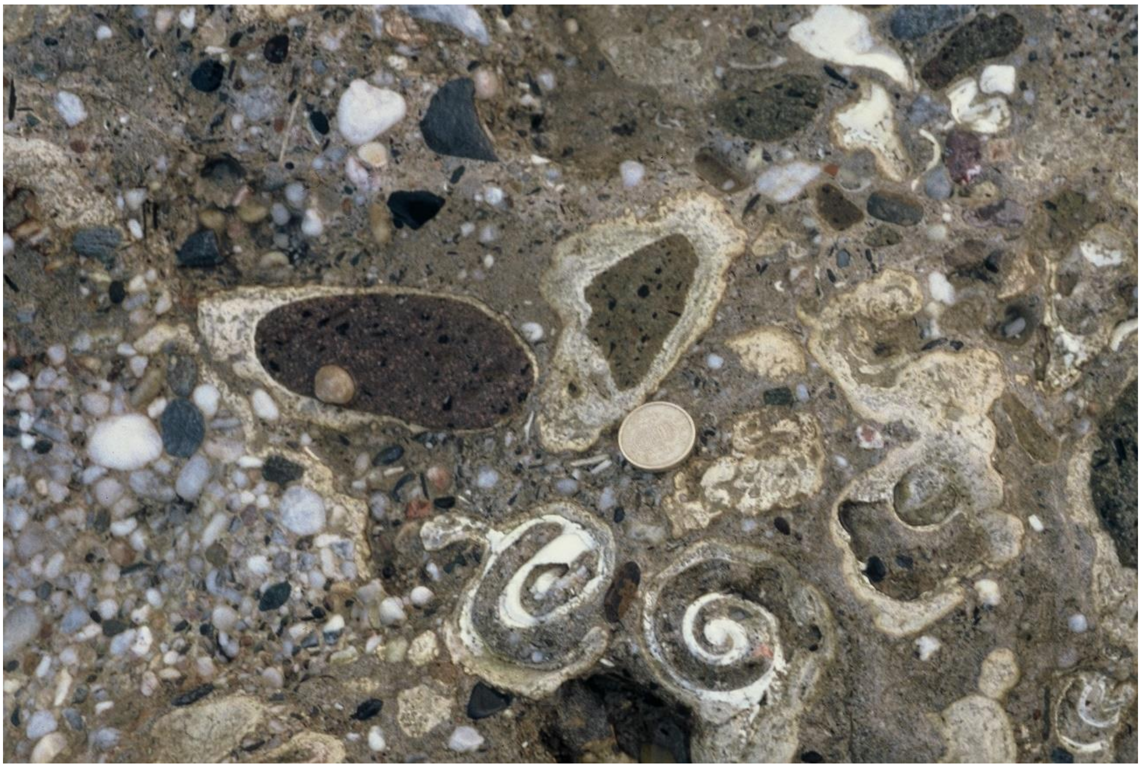
Photograph 199.- Close view of the algal crust partly covered by the quartz-rich conglomerate (Carboneras).

Photograph 200.- The algal crusts include as well some small detrital grains (Carboneras).

Photograph 201.- Well-rounded quartz clasts (c) make up the bulk of the conglomerate together with schist (e) and volcanic-rock clasts (rv). Some oolites are present in the sandy matrix of the conglomerate, although they are only visible under the microscope (Carboneras).

Photograph 202.- Well-preserved *Strombus bubonius*-gastropod skeletal remains are also found in the conglomerate (Carboneras).

Photograph 203.- Some *Strombus bubonius* specimens are exceptionally well-preserved (Carboneras).



Photograph 204.- Some conglomerate clasts and gastropod (*Strombus*) fragments are encrusted as well by coralline algae (Carboneras).

Photograph 205.- Fossil oolite beaches, developed at the same time as the Carboneras rocky-shores, are to be found in some Cabo de Gata localities (Rodalquilar y Los Escullos). Contemporaneous, fossil, Quaternary aeolian oolite-dune deposits exhibiting a conspicuous cross bedding occur as well, as shown in the picture (Cabo de Gata. Los Escullos).

Photograph 206.- Los Muertos beach has a presumably fault-controlled, linear (straight) trending. The cliff nearby is made up of volcanic rocks (volcanic agglomerates). The beach sediment, by contrast, consists of a granule- to pebble-sized conglomerate with abundant quartz clasts, which derived from Sierra Cabrera, placed some ten kilometres to the north. Sediment is transported by longshore currents (linked to eastern storms) from Sierra Cabrera up to Los Muertos beach (Carboneras). →

Present-day coastal sediments

Photograph 207.- San Pedro beach. Beach (foreshore) sediment is a pebble-sized conglomerate. It fines out to seawards (at the shoreface) to sands (Cabo de Gata. San Pedro).

Photograph 208.- Conglomerate beach (foreshore)-deposit, with large, volcanic-rock blocks changing into a sandy deposit to seawards (at the shore face). A climbing, aeolian sand dune occur at the backshore on top of the volcanic relief (Monsúl beach. Cabo de Gata).

RECOMMENDED ITINERARIES:

Itinerary 5.- Sopalmo-Mesa Roldán-Cañada Méndez-El Plomo-Cala Carnaje

Most stops are by the road. It can be done by car with only some small walking.
Main subjects: Emplacement, significance and typology of the volcanic rocks of the Cabo de Gata Complex. Role of major strike-slip faults. Sediment-volcanic rock relationship. Intravolcanic sedimentary sequence: the Tortonian temperate carbonates.
Duration: one day.

Location map

Stop 1.- Sopalmo (a-b):
Observed features: (a) 100 y 101; (b) 102, 105 and 106.

Stop 2.- Mesa de Roldán:
Observed features: 107.

Stop 3.- Cañada Méndez (a-b):
Observed features: (a) 108, 109 y 114; (b) 110, 111, 112 and 113.

Stop 4.- El Plomo:
Observed features: 115 and 116.

Stop 5.- Cala Carnaje:
Observed features: 117, 118, 119 and 120.

Itinerary 6.- Agua Amarga (Los Murcias-Las Cordilleras-Rambla de los Viruegas)

Most stops are by the road. It can be done by car with only some small walking.
Main subjects: temperate carbonates from the Tortonian-Messinian transition in the Agua Amarga basin.
Duration: half a day.

Location map

Stop 1.- Los Murcias:
Observed features: 121.

Stop 2.- Las Cordilleras (a-b):
Observed features: (a) 122; (b) 123, 124, 125, 126, 127 and 128.

Stop 3.- Rambla de los Viruegas:
Observed features: 129, 130 and 131.

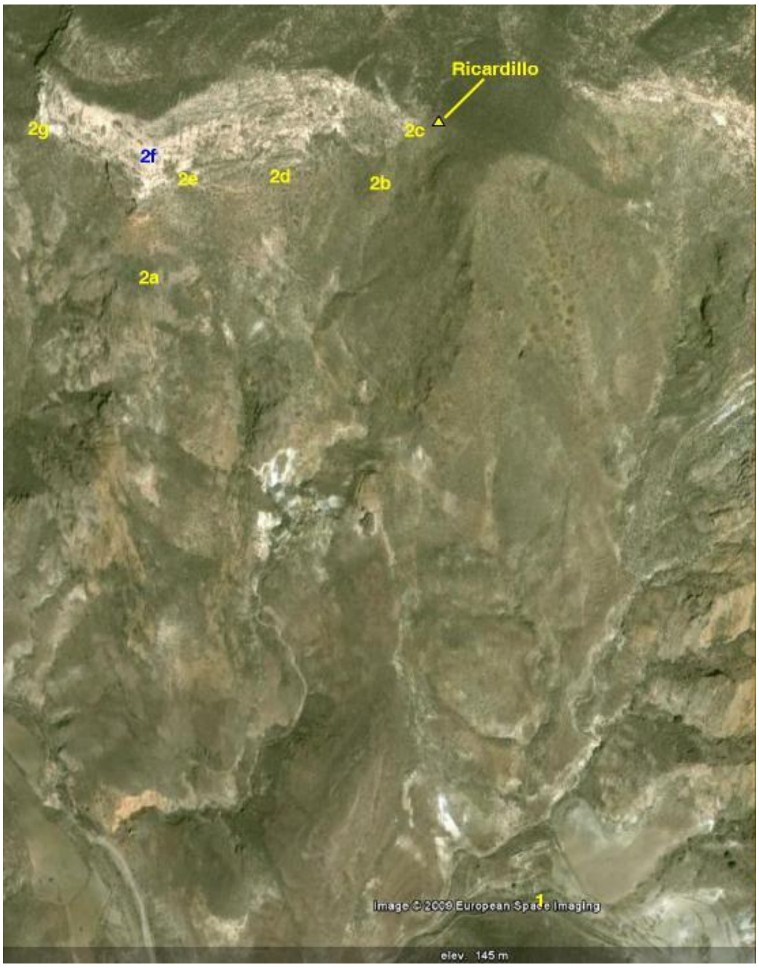
Itinerary 7.- Ricardillo

The Cortijo del Ricardillo (Ricardillo farm) can be reached by car from Las Negras following the dirt road to the village sewage plant. The rest of the trip must be done on foot. The climbing to the Ricardillo-hill top is somehow difficult and required some physical effort.

Main subject: Temperate carbonates from the Tortonian-Messinian transition: cliff and small coastal-depression facies.

Duration: one day.

Location map



Stop 1.- Cortijo del Ricardillo (Ricardillo farm):
Observed features: 132.

Stop 2.- Ricardillo (a-b-c-d-e-f-g):
Observed features: (a) 134; (b) 103 y 133; (c) 139, 140, 141 y 142; (d) 135 y 136; (e) 137, 138 y 146; (f) 147 y 148; (g) 143, 144 and 145.

Itinerary 8.- Las Negras-Mesa Roldán

Most stops are by the road. It can be done by car with only some small walking.
Main subjects: Messinian reefs.
Duration: half a day.

Location map

Stop 1.- Rambla del Cuervo (Las Negras):
Observed features: 149, 150, 151, 152 and 153.

Stop 2.- La Chumbera:
Observed features: 154.

Stop 3.- Mesa Roldán:
Observed features: 155, 156, 157, 158 and 159.

Itinerary 9.- Carboneras-Rellana de las Contraviesas-El Castillico-Los Muertos
Most stops are by the road. It can be done by car with only some small walking.
From stop 4-7 (from the “El Castillico” to the “Los Muertos”) the road to take is unpaved (it follows the old, abandonned Lucainena-mines railway) and a 4-wheels drive vehicle is recommended.
Main subjects: Lower Pliocene temperate carbonates.
Duration: one day.
Location map

Stop 1.- Puerto de Carboneras (Carboneras fishing harbour):
Observed features: 160 and 161.

Stop 2.- Loma del Pinico (a-b):
Observed features: (a) 162 y 163; (b) 164 and 165.

Stop 3.- Rellana de las Contraviesas:
Observed features: 167, 168, 169, 170, 171, 172 and 173.

Stop 4.- El Castillíco:
Observed features: 178, 179, 180, 181, 182 and 183.

Stop 5.- Las Covaticas:
Observed features: 166 and 184.

Stop 6.- Old Lucainena-mine railway trench:
Observed features: 185, 186, 187, 188, 189 and 190.

Stop 7.- Los Muertos (a-b-c):
Observed features: (a) 174; (b) 175; (c) 176 and 177.

Itinerary 10.- Carboneras

All stops are by the road. It can be done by car.

Main subject: Quaternary rocky shores and beaches.

Duration: a quarter of a day.

Location map

Stop 1.- Central Térmica de Carboneras (Carboneras Power Station):
Observed features: 193 and 194.

Stop 2.- Playa del Lacón (Lacón beach):
Observed features: 195, 196, 197, 198, 199, 200, 201, 202, 203 and 204.